Research Monograph

The Climate Change and Energy Debate in Ethiopia

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ABSTRACT

Ethiopia is a predominantly rural nation, but like much of East Africa is urbanizing at a rapid rate. By 2030, a full third of Ethiopia's population will live in cities, placing increasing pressure on urban service delivery and governance systems. Given Ethiopia's projected population growth, this amounts to an estimated 40 million or more living in cities across the country in the next two decades.

Ethiopian cities are already under pressure from the more than 15 million living in urban areas (2012), and are unable to provide the urban population with access to basic services, including water and sanitation and energy. In the absence of adequate, affordable urban services, a growing urban population translates into growing urban poverty. Cities in Ethiopia are already characterized by informal settlements and resource-poor communities living in harsh conditions; the growth of population in secondary cities, spurred especially by the very visible trend of urban-to-urban migration in Ethiopia, could lead to rapid growth in urban poverty.

One of the strongest manifestations of urban poverty is the lack of adequate energy services. While almost all urban areas in Ethiopia, including all its secondary cities, are connected to the national grid, actual use of modern energy sources is still lagging. Urban populations appear to be using electricity mainly for lighting. But, despite the relatively low cost of electricity in Ethiopia, several factors are preventing communities from leveraging electricity access as an economic resource to enhance productivity. These factors include the lack of reliable electricity supply (mainly the result of poor-quality, aging grid infrastructure that lends itself to blackouts) and the cost of electrical appliances. However, one of the single most important factors keeping urban populations in Ethiopia from reliance on electricity is the cultural attachment to traditional forms of cooking, in the form of biomass-based cook stoves (charcoal and fuelwood). The use of these stoves has enormous public health and environmental consequences.

Besides urban households (both direct users and those who source power through secondary connections), the largest consumer of energy in Ethiopian cities is industry. Several cities are home to highly energy-intensive industries such as cement production, which account for a vast share of Ethiopia's greenhouse gas (GHG) emissions. Most industries rely on fossil fuels for thermal energy to support industrial processes.

Energy demand and use in Ethiopia's secondary cities are likely to increase as more people migrate to cities and as income levels rise. But supplies of biomass energy and hydropower,

Ethiopia's main sources of energy, are susceptible to shocks from climate change. Biomass, for instance, is already facing a reduction in supply because forest cover has retreated after decades of exploitation; fuelwood is now sold in kilograms, rather than in heaps as it used to be, and has become increasingly expensive. Ethiopia's energy sector must rise to the challenge of providing more reliable, healthy and affordable electricity access to Ethiopians (including urban populations) over the next 20 years, so that electricity can be used as more of an economic good and can bring benefits to all segments of society. In addition to meeting these needs, the sector must simultaneously evolve into a more climate-resilient system that is robust to variability and that ideally does not contribute significantly to climate change, to the population's disease burden, or to other environmental and social externalities.

Ethiopia (and by extension Ethiopian cities) can turn to alternative power sources for a more diverse electricity mix that includes solar, wind and geothermal sources. Urban settings may also be well suited to changing Ethiopians' reliance on traditional cooking styles. Increasing the proportion of clean energy in the mix can even create new value chains and economic opportunities that support inclusive growth. But several barriers at the national and city levels may thwart a strong pivot towards modern energy, including regulatory barriers, price and market barriers and cultural barriers.

Ethiopia's efforts to overcome the barriers (both for industrial and household energy use) can be informed by successful approaches in other East African and African countries that share a similar context, and in turn can inform approaches in other countries grappling with inadequate and unsustainable urban energy service delivery.

EXECUTIVE SUMMARY

Ethiopia is one of the fastest-growing countries in Africa, in terms of both economics and demographics. In coming decades, the country is going to undergo rapid change, transitioning from a Least Developed Country (LDC) to a developing economy. In many parts of Africa, this shift has brought with it changes in the rural-urban continuum in the form of greater urbanization. Ethiopia is poised to experience the same.

Ethiopia currently has a low level of urbanization (that is, percentage of total population residing in cities and urban settings), but it is displaying a rapid rate of urbanization (that is, the pace at which people are relocating to cities). This trend towards urbanization has also been accompanied by a spatial trend; land area covered by cities has expanded significantly, with rural land on the outskirts of cities being increasingly subsumed into cities. Urban residential areas, in particular, have been expanding, extending city boundaries ever further.

Swelling residential communities in Ethiopian cities call for a commensurate increase in residential service delivery, including for essential services like energy. However, service delivery has not kept pace with increased urbanization. In terms of access to services such as water and sanitation, populations are underserved. In the context of energy, the picture is more complex, with statistics suggesting that urban populations enjoy the necessary access. However, there are significant nuances to the manner in which this situation is assessed, and estimates suggesting that most urban residents have access to electricity stand apart from a vast literature that notes a lack in Ethiopian urban service delivery.

The government's own figures indicate that 60 per cent of urban areas are classified as impoverished zones, devoid of or sorely lacking adequate access to basic services. A quarter (25 per cent) of urban dwellers live below the poverty line. Ethiopia has yet to witness the benefits that may accrue from urbanization; population aggregation in cities can often lead to agglomeration of resources and greater productive efficiency. Urbanization can also spur modernization and scaling up of the agricultural sector in the hinterlands through creation of greater demand for agricultural supplies to cities. This transformation has not occurred in a marked way in Ethiopia, and part of the reason may be that urban populations are still too under-served and lack the income levels that can fuel such economic growth in cities.

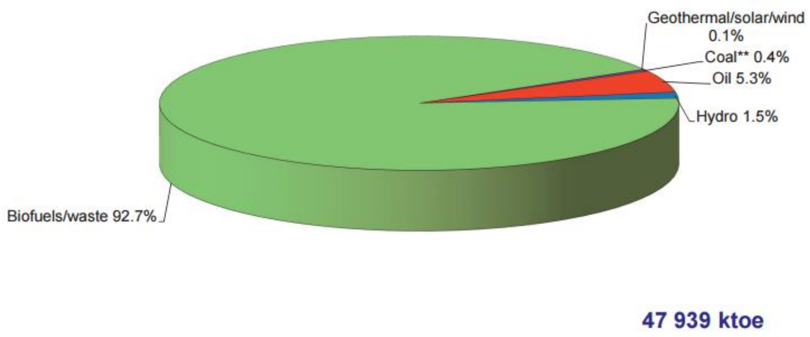
Within this larger picture, Ethiopia's secondary cities are important locations. The majority (75 per cent) of Ethiopia's urban population does not live in a primary city like Addis Ababa (which is home to a quarter of Ethiopia's urban residents), but is spread across 12 secondary cities.

Climatically, Ethiopia sits in a largely arid zone. Rainfall occurs in two seasons, June through September, and a shorter spell from March through May. Ethiopia has seen significant temperature rise in recent decades. Rainfall trends in recent decades are plagued by greater uncertainty, and there is evidence to suggest an overall decline in total annual rainfall volumes. Extreme weather events have become more common, especially droughts (which in turn may trigger famine). At the same time, flood events have also become more common. In 2016, the rainy season hadn't even taken hold when Diré Dawa, a secondary city in Ethiopia (and one of two case study cities for this paper), started experiencing major flooding. Ethiopia is ranked 5th of 184 countries for drought risk, 34th of 162 countries for flood risk, and 5th of 152 for landslide risk. These are dangers that Ethiopians residing in secondary cities need to grapple with.

A glimpse into the future suggests even more challenging climatic conditions, with climate change exacerbating the levels of variability Ethiopia already experiences. There is a high level of confidence in future temperature projections that point toward a significant warming trend. With rainfall, projections remain tricky, but most models lean towards more rainfall (that is, greater volumes of total annual rainfall), with rain expected to fall in heavier rainfall events interspersed with droughts and dry stretches. It is anticipated that rainfall variability will increase across the country, with even greater incidence of extreme weather events. Of concern is the fact that, even in global low-emission scenarios that depict modest planetary warming, Ethiopia is likely to experience higher than average temperature rises and related impacts. The secondary cities of Diré Dawa and Mekelle mirror the national trend and are expected to see temperatures rise and rainfall volumes increase, but with heightened variability and extremes. Diré Dawa is likely to be more prone to floods, while Mekelle may witness a disproportionate increase in droughts because of its proximity to the highlands.

Climate change in Ethiopia – overlaying an already problematic trend of growing population density in certain areas, the absence of vast amounts of fertile land to be cultivated, and a decrease in landholding size – poses a threat to food security and agricultural livelihoods. The World Bank suggests that climate change could reduce Ethiopia's gross domestic product (GDP) by as much as 10 per cent by the year 2045. Negative impacts of climate change disproportionately affect women. Other vulnerable groups in Ethiopia are smallholder farmers (including those cultivating small parcels of land on the fringes of cities) and the urban poor. In terms of the contribution of Ethiopian cities to climate change, cities currently represent only 15 per cent of Ethiopia's total emissions. This figure is expected to rise to a 35 per cent share by 2030, driven by growing transportation and energy needs in cities.

Ethiopia's current energy profile reflects a staggering dominance of bio-energy (as shown in the figure below). Biomass constitutes approximately 90 per cent of total final energy consumption, fossil fuels account for 8.5 per cent, and electricity only 1.5 per cent. Among the major users of energy, households in Ethiopia represent 91 per cent of all energy consumption, while the transportation sector accounts for 6.3 per cent. The services and industrial sectors constitute less than 2 per cent each of Ethiopia's total energy use. Ethiopia currently consumes an estimated 65 kWh per capita per year, which lags many of its contemporaries, including Kenya (168 kWh/capita/year), Tanzania (89 kWh/capita/year), Cameroon (278 kWh/capita/year) and Mozambique (436 kWh/capita/year). However, current electricity demand growth is more than 25 per cent per annum, one of the highest growth rates in Africa.

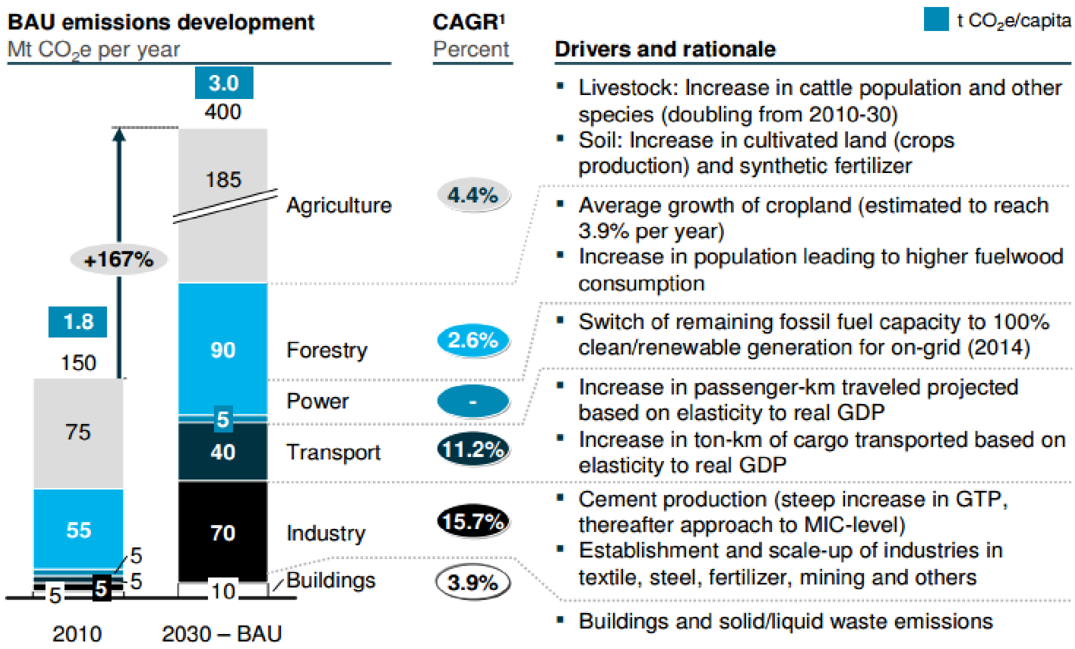


Total Primary Energy Supply in Ethiopia in 2013

All secondary cities in Ethiopia are connected to the national grid. However, actual power usage is low. According to 2011 figures, 96 per cent of households in secondary cities used electricity for lighting, but only 14 per cent used it for cooking. Three-quarters of households in secondary cities used traditional biomass for cooking. This picture is slowly changing, but biomass remains a fundamental source of energy for cooking. This is particularly noteworthy, given that official estimates suggest over 90 per cent grid connectivity of households in cities like Diré Dawa and Mekelle. Households in such cities are not, evidently, deprived of access to electricity (even though many households derive power through secondary connections, purchasing power from neighbours with a metered connection). It has been surmised that secondary power purchases make electricity more expensive, thereby acting as a disincentive for many Ethiopian city-dwellers to run large electric appliances. This picture seems untenable in the face of increasing urbanization, with the population of secondary cities expected to double in the next 20 years and energy demand in secondary cities starting to resemble that of Addis (which is unfortunately prone to major, recurrent power outages).

Industrial energy demand is an important component of urban energy consumption in Ethiopia. Approximately 60 per cent of the country's medium and large manufacturing industry is in and around secondary cities, and the same is true of more than 80 per cent of small-scale industries. Medium- and large-scale industries are responsible for 90 per cent of total energy consumed in the manufacturing sector, with this energy derived mainly from fossil fuels (64 per cent), then electricity (21 per cent) and biomass (15 per cent). Among the large industries, cement factories are the main consumers of energy, in the form of petroleum coke and coal for thermal energy. This fact also holds true for the two case study cities of Diré Dawa and Mekelle. Industrial parks being developed in Diré Dawa and Mekelle (and other secondary cities) will likely increase energy and power consumption in these areas.

The business-as-usual emissions growth is indicative of the energy and emissions mix that may arise without a shift to a lower-carbon energy mix for transport, industry and buildings.



Greenhouse Gas Emissions from Ethiopia (Business as Usual)

Hydropower dominates Ethiopia's current electricity mix. It accounts for approximately 1,940 MW of generation capacity, compared to 324 MW of wind, and 143 MW of diesel (geothermal power has only 7 MW of capacity). Given the country's heavy reliance on hydropower, climate change and variability are a key concern for the reliability and consistency of hydroelectric power generation and supply. Climate change models suggest a future increase in variability. While wet season river flows are expected to increase, dry season flows may be negatively affected in some river basins. Hydrological models factoring in climate change are still at a nascent stage of development in Ethiopia, but a few initial studies do indicate that changes in timing and flows need to be factored into hydropower supply in coming years.

Over-reliance on one source of power is not optimal for Ethiopia's energy security. With the potential of climate change to further complicate hydrological flow regimes, there is an even greater need for diversity in the country's electricity mix. Hydropower, a low-carbon energy source, will justifiably remain a primary source of electricity (potentially with storage), especially given that Ethiopia has thus far exploited only a mere 10 per cent of its total hydro potential. However, diversifying the source, location and temporal availability through creating a complementary electricity mix could allow power supply in Ethiopia to be more dependable. A new power supply regime coupled with much-needed infrastructure repairs, maintenance and grid upgrades would help reduce current power interruptions and potentially make electricity a more attractive option for households and businesses to harness for their energy service requirements. Thus, for the power sector, there is a need to develop alternative sources of electricity.

Similarly, there are also several arguments for the development of alternative non-electrical fuels for thermal energy to spur a shift away from biomass for cooking. Reliance on biomass (such as charcoal or fuelwood) is notorious for it negative effects on the health of its users (who are predominantly women). From a public health perspective, a shift away from conventional biomass for cooking may reduce mortality and morbidity from respiratory disease in Ethiopia. Unsustainable or improper collection of biomass also has detrimental ecological consequences, potentially contributing to deforestation and land degradation.

There is therefore an argument for growth of non-hydro renewable energy sources, both to supplement growing hydropower (as Ethiopia harnesses more of its 30-40 GW of generation potential, most of it on the River Abay, or Blue Nile) and to displace biomass in household energy use. In terms of resource potential, Ethiopia has several alternative, low-carbon energy sources to choose from. It is currently tapping into less than 1 per cent of its potential of solar, wind and geothermal energy. It has sizeable potential for all three. Given the power system's ability to retain hydro as a source of baseload power (and potentially pumped storage in the highlands), Ethiopia can add more intermittent power sources from solar and wind into the mix. It can also harness, if needed, natural gas reserves in the east of the country, to provide peaking power. While natural gas is a fossil fuel and cannot be viewed as a low-carbon source, it is relatively less carbon-intensive than diesel or coal and, if well managed and directed, can play a role in supporting the growth of renewables.

In the context of biomass, alternatives include both sustainably produced bio-ethanol (such as from molasses), briquettes from sustainably harvested and collected sesame waste, and electric cooking. All of these are already present in the Ethiopian market but need to be significantly scaled up. Furthermore, municipal waste-to-energy plants and cogeneration in cement and steel plants are also promising alternatives that should be explored further.

The estimated potential and level of exploitation of the various indigenous resources are given below, highlighting the many possibilities for using renewables in a future energy mix.

Summary of Indigenous Energy Resource Potential and Current Level of Exploitation in Ethiopia

Resource	Unit	Exploitable Reserve	Exploited Percent
Hydropower	MW	45,000	< 10%
Solar	$kWh/m^2/day$ (TWh/annum)	Average 5.5 (2.2 million) - (Derbew, 2013)	< 1%
Wind: Power (Speed)	GW (m/s)	1,350 (>6.5)	< 1%
Geothermal	MW	7,000	< 1%
Wood	Million tons	1,120	50%
Agricultural waste	Million tons	15 - 20	30%
Natural gas	Billion m^3	113	0%
Coal	Million tons	> 300	0%
Oil shale	Million tons	253	0%

Ethiopia has already committed itself to the pursuit of low-carbon development, through its Climate Resilient Green Economy Strategy and its Intended Nationally Determined Contribution (INDC), submitted to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat. Ethiopia’s Power Sector Development Plan also targets renewables growth in the coming decade. However, development of renewable energy in Ethiopia faces several challenges.

One challenge is cost. For low-carbon energy to grow at the pace and to the scale identified in Ethiopia’s Power Sector Expansion Plan (through the year 2037), the cost would be several billion dollars. One of the most successful ways that countries (including Kenya, South Africa and Namibia) have dealt with costs is to allow the private sector to drive growth in the renewables industry and to invest private capital to develop low-carbon energy. Ethiopia should consider this pathway.

Ethiopia’s existing power (mainly hydro-electric) is heavily subsidized. This artificial cost makes non-subsidized non-hydro renewables less competitive. Additionally, Ethiopia’s current grid is inadequately maintained, and grid quality and stability are already matters of concern, making the integration of renewables a heightened challenge. On the biomass side, an important factor that has slowed down the uptake of cleaner cooking alternatives is the customary attachment to traditional cooking forms, particularly for Ethiopia's staple food, injera (a type of bread).

The biggest challenge of all, however, is a regulatory one. Robust growth of clean energy in Ethiopia would require investment from the private sector (primarily from outside the country), but Ethiopia's experience with independent power producers (IPPs) is very new. Ethiopia's power system is a vertically integrated, single-buyer system, where power generation, sale, distribution and transmission are all within the domain of the state power agency, Ethiopian Electric Power (EEP). This market structure prevents individuals and enterprises from independently investing in clean energy generation to serve local needs (or to sell to bulk consumers interested in localized renewable energy instead of off-take from the grid). While there are a few initial IPP projects underway in Ethiopia (authorized on a case-by-case basis), these projects still sell power back to the national utility. Under the current regulatory framework, there is no scope for a distributed generation model, that is, where an entity produces renewable energy from (typically) small-scale projects and supplies this to consumers who are either not connected to the grid or who would choose to supplement grid-based power with renewables. The prevailing framework severely limits the potential role of the private sector.

In the context of secondary cities in Ethiopia, this regulatory barrier prevents cities and municipal governments from making choices about how to meet their own growing energy demand and curtails their agency in commissioning low-carbon energy projects to serve local needs. Being empowered with greater choice and the ability to pursue energy self-reliance would enable local governments to direct adequate energy towards economic activities and social infrastructure that could support inclusive growth.

As electricity prices in the East African Power Pool (EAPP) go up (as they are expected to), and as it becomes more challenging for Ethiopia to continue subsidizing its electricity, the government is likely to encourage renewables development. There is already talk of a Renewable Energy Feed-in-Tariff (REFiT) program, where the government would assure private developers that they will be able to sell renewable energy they generate to the government at a specific tariff for a specified number of years (thereby allowing the developers to recoup their costs over time through power sales). Introducing mechanisms such as net metering would enable embedded generation, that is, for individuals or enterprises to generate electricity on-site and to sell excess power not consumed to the national utility. This move could also facilitate the growth of localized energy generation and supply in Ethiopian secondary cities and allow for more income generation by urban residents in the form of revenue from sell-backs. However, such a move would require considerable changes to the structure of the Ethiopian electricity market, and would rely on regulatory transformation to become feasible.

The benefits of developing low-carbon energy sources are numerous, but in the case of Ethiopia an accurate estimation of such benefits necessitates a range of further research and assessments that is beyond the scope of the current inquiry. Critical future research that would aid robust analysis of the issues dealt with in this monograph, while gauging the potential tangible and intangible benefits from clean energy for inclusive growth in secondary cities, include (but are not limited to) the following:

- More localized and country-specific climate change projections, based on a richer network of hydro-meteorological stations, more robust and reliable data, and with higher resolution.
- Energy demand projections based on modelling that factors in future climate change impacts such as rising temperature on demand for space-cooling, electrical system load and stability.
- an investigation into the urban development agenda in Ethiopia, including an analysis of the prevailing urban planning paradigm in Ethiopia, which could help identify how low-carbon development could be mainstreamed into urban planning to ensure that cities develop in a resource efficient manner; this would strengthen the case for diversified and low-carbon energy mix, while addressing developmental challenges in a more sustainable manner.
- A comprehensive needs assessment to support the development of a national renewable energy policy (which would further current efforts to research the impacts of a standardized IPP framework and a feed-in-tariff).
- A sociological and statistical study to understand better why households in Ethiopian secondary cities that have access to affordable grid-based electricity still do not choose to use electricity for cooking, and continue to rely on biomass.
- Economic analysis of benefits (health, environment, social welfare) from low-carbon energy use in cities, including economic externalities.
- An investigation of low-carbon energy financing options for cities in Ethiopia and comparative models from other African cities to understand future financing options better.

- Economic opportunities for cities (potentially a cost-benefit assessment and a detailed feasibility assessment) such as employment, derived from a scaling up of low-carbon energy sources.
- A grid-integration study to determine ability of existing grid to absorb more intermittent renewables.
- A study to evaluate clean energy options for large industry (such as cement), including captive plants.
- A detailed study of the effect of subsidies and other government policies on energy costs and electricity pricing, to explore competitiveness of non-hydro renewables in comparison to hydropower and fossil fuels (with and without subsidies, and with a dynamic pricing structure).

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Project Background and Methodology

Overview

After the introductory section, which sets out the research objectives, hypothesis, methodology and investigation timeframe, the monograph is divided into eight chapters.

Chapter 1 covers the changing face of Ethiopia's cities, implications of urbanization and the particular significance of secondary cities, and introduces the case study cities of Diré Dawa and Mekelle. This chapter also discusses the status quo of institutional arrangements, governance structures, and approach to urban planning of cities in Ethiopia.

Chapter 2 describes the changing climate (climate variability, climate change and impacts on society) and the need for a climate-resilient energy supply in the face of increasing energy demand.

Details of Ethiopia's energy sector, including current and future supply and demand, particularly in secondary cities, are presented in Chapter 3, together with considerations for climate change resilience and low-carbon development (options, regulations, planning, costs and policies).

Chapter 4 looks at the potential for inclusive growth in future Ethiopian cities through an energy services lens by looking at the merits of low-carbon energy options. This is supplemented by three regionally relevant country comparisons.

A diversified, low-carbon, optimal energy mix is discussed in Chapter 5, looking at current and future energy requirements, infrastructure needs and financial and trade implications.

In Chapter 6, the two city case studies are analysed in terms of their respective climate profiles and climate change trends, energy profiles and energy trends. Observations drawn from the case study cities are also briefly explained in this chapter.

Chapter 7 concludes the research by outlining potential actions to support the emergence of more low-carbon energy options in cities as a means of underpinning climate-resilient inclusive growth, and notes the additional research needs required to provide an impetus to this transition.

Chapter 8 provides a list of works cited in the research monograph, and precedes an Appendix containing additional data on the case study cities.

Research Objectives

The aim of this project is to conduct an "***investigation of viable alternative energy choices that can support inclusive growth of secondary cities in Ethiopia, taking into account future climate change and the need for environmentally sustainable, low-carbon, and universally accessible energy sources."***

The objective of this project is to produce rigorous, actionable research that can shed light on options and opportunities for cities in Ethiopia to meet growing energy demand, and to do so in a manner that is conducive to a clean energy future and socio-economic equity. The aim is to empower cities in Ethiopia with key information on how to make (and potentially accelerate) the transition to a low-carbon future, while simultaneously meeting cities' development needs (and contributing to socio-economic betterment for all cities' inhabitants). The research investigates the impacts of climate change on Ethiopia's energy resources (particularly hydropower, which is susceptible to significant systemic negative climate change effects on river basins as well as extreme events like floods and droughts).

The primary goal of this research is the generation and dissemination of high-quality research that puts forward, tests and evaluates hypotheses about energy choices of cities in Ethiopia considering climate change. The research integrates case studies from Diré Dawa and Mekelle, but also includes insights from cities in Mozambique and Uganda.

Definition of Key Terms

Low-Carbon Energy Technologies: Technologies that produce low or zero GHG emissions in the conversion of primary energy into useful energy for meeting the demands of end-users. In the power sector, this includes fossil-fuel plants fitted with carbon capture and storage (CCS), nuclear plants and renewable-based generation technologies (IEA, 2016).

Renewable Energy: Energy that is derived from natural processes (for example, sunlight and wind) that are replenished at a higher rate than they are consumed. Solar, wind, geothermal, hydro and biomass are common sources of renewable energy (IEA, 2016).

Sustainability Meeting the needs of the present without compromising the ability of future generations to meet their own needs (World Bank, 2001).

Inclusive Growth: Growth that takes place in the sectors in which the poor work; occurs in places where the poor live; uses the factors of production that the poor possess; and reduces the prices of consumption items that the poor consume (UNDP, 2015). Inclusive growth refers to both the pace and pattern of growth, which should be interlinked. Inclusive growth is about raising the pace of growth and enlarging the size of the economy while levelling the playing field for investment and increasing productive employment opportunities. Inclusive growth approaches take a long-term perspective (World Bank, 2009).

Secondary Cities: Secondary cities often have populations ranging from 10 per cent to 50 per cent of a country's largest city. Most have populations between 100,000 and 5 million, depending on the size of the country, although a few are smaller or larger than this. Secondary cities include sub-national urban centres of administration, manufacturing, agriculture or resource development; metropolitan-clustered secondary cities, which develop on the periphery of metropolitan or urban regions and take the form of new towns, spill-over growth centres and linear cities; and corridor secondary cities, which develop as growth poles along major transportation corridors (Roberts, 2014).

Environmentally Responsible Growth: Growth that accommodates population growth while minimizing negative impacts on natural resources (New Hanover County Comprehensive Plan, 2015).

Research Hypothesis

The research inquiry of this project is to investigate whether, and if so the degree to which, secondary cities in Ethiopia (such as Diré Dawa and Mekelle and others like them) can rely on low-carbon, sustainable, environmentally responsible sources of energy to underpin and support climate-resilient, inclusive growth over the next few decades.

In other words, are low-carbon energy sources viable choices for such cities, allowing them secure, affordable, uninterrupted energy that keeps pace with growing demand, so that they can ensure growth that benefits all while promoting social and economic equity and wider opportunities?

Our hypothesis was that a low-carbon transition is indeed technologically and economically viable. Our task was to test this hypothesis, and though we have found evidence to support it, we have also discovered that non-technological or economic barriers are the most significant constraints. Specifically, it is the current regulatory framework in Ethiopia that restricts cities from having greater agency in their energy choices.

In summary, our research hypothesis was framed as: **"Secondary cities in Ethiopia (such as Diré Dawa, Mekelle and others like them) can rely on low-carbon sources of energy to meet energy demand and to underpin and support climate-resilient, inclusive growth to 2035."** Our findings are that this is indeed possible, but would require regulatory reforms in the energy sector, as well as the devolution of greater decision-making powers to cities, coupled with enhanced institutional capacity at the city level.

Timeframe for Investigation

The research team considered the period during which the research query should apply. While there was a temptation to investigate longer timeframes (such as through mid-century) with the hope that the research would have greater relevance over a longer period, we recognized that making the research as relevant, actionable and reliable as possible actually requires focus on a more proximate range of dates. Beyond a 20- to 25-year time horizon, climate change projections become prone to greater uncertainty. Additionally, for this research to be aligned with Ethiopia's many development plans and for it to have a chance for integration in the government's own planning efforts, it should speak to similar timeframes that are of interest to planners. Critically, renewable energy technologies, the technical and economic viability of which we investigated, evolve rapidly. Given that the nature of low-carbon technologies may be significantly different after a few decades (with current technologies becoming obsolete and current financial approaches no longer viable), a timeframe of 20 years appeared to be most reasonable. Finally, our initial literature review and data gathering demonstrate that the broad range of information we would rely on for this project (urban growth, population shifts, demographics, energy consumption and demand, energy investment, land-use planning and so on) is richer and more robust in the 20- to 25-year timeframe, and data become sparser in the period beyond that timeframe.

Based on all these considerations, we chose 2035 as the end date for the current inquiry.

Research Methodology

The research project relied predominantly on a literature review of secondary information, that is, published reports, documents, data from official sources, and scholarly publications. To this end, the team relied on peer-reviewed publications as well as official government records.

Two secondary cities were selected for this study, namely Diré Dawa and Mekelle. Based on the significant rate of urbanization in Ethiopia overall (World Bank Group, 2015), as well as current urbanization and energy demand trends in each city, it is projected that future demand for land and urban services, will be significant within the Diré Dawa and Mekelle regions. For this reason, they are apt case studies, and understanding urban trends and demand in these two cities will offer invaluable insights into enhancing future urban resilience in these regions.

This secondary material survey was supplemented by primary research methods such as in-person interviews with researchers and policymakers. Such interviews, in Addis Ababa, Diré Dawa and Mekelle, enabled collection of valuable information and insights that are not available in published sources. These engagements also enabled validation of emerging findings.

Additionally, the primary research methods included four in-country workshops at which facilitated discussions on the research topic and several underlying research questions took place. At such events, the presence of subject-matter experts allowed for the research team to elicit key information that is not reflected in published material.

1. The changing face of Ethiopia's cities

1.1. Introduction

A considerable body of knowledge exists in relation to urbanization in Ethiopia and more widely in Sub-Saharan Africa (Dijk & Fransen, 2008;) (Schmidt & Mekamu, 2009) (World Bank Group, 2015). This appears to be a field that has attracted some study, and the available resources are a fair mix of academic research and reports by international NGOs, multilateral development organizations, and country governments (with the latter sources far more visible and prolific). The available research, however, focuses on the national level rather than the city level. Information and scholarly research on Diré Dawa and Mekelle, for instance, is relatively scant and inadequate.

The concept of "secondary" or "intermediate" cities has recently gathered significant attention within the research community. As such it is an emerging field and focus area in urban studies, particularly in the African context. It should be acknowledged that the concept of secondary cities is a comparative term that describes the size and functions of cities relative to each other, emphasizing the role of these cities within the spatial economy of the country (John, 2012) (Roberts, 2014). In the case of Ethiopia, Addis Abba is the dominant city; the next largest cities, Diré Dawa and Mekelle, are significantly smaller. This chapter aims to unpack the nature of these urban dynamics and the functional roles of each of these secondary cities. An understanding of these concepts will indicate where the energy needs of these cities lie at present, relative to a much larger city like Addis Ababa, and will also help the reader understand how the energy needs of these cities may change into the future.

A study of Ethiopian urban trends and demographics reveals that Ethiopia currently has a relatively low level of urbanization and still has a large and dispersed rural population. However, from this low urban base, the country is currently experiencing a relatively rapid rate of urbanization (Schmidt & Mekamu, 2009). It is speculated that much of the urban growth in Ethiopia is likely to occur in secondary cities, which have fewer resources and weaker capacity to meet growing population demands, within a context where urban population growth has outpaced an expansion of basic services. This expected urban population growth affects energy demand and provision and emphasizes the need for Ethiopian cities to ensure that growing energy needs are supported in a sustainable manner.

1.2. Understanding urbanization

Urbanization describes the proportional increase in the number of citizens living in urban environments (that is, towns and cities) and is most often characterized by the movement of people from rural areas to these urbanized places. The rate of urbanization and the infrastructure and services needed to support living and working environments have already presented African nations with major challenges in the past few decades. These services include appropriate levels of energy provision for an increasing number of inhabitants and industries. It is becoming increasingly clear that these challenges are, and will continue to be, exacerbated by the impacts of climate change, adding immensely to the vast complexity of such urban challenges (UN HABITAT, 2014).

A key component of ensuring well-serviced urban environments is land management and urban planning. If urbanization is properly managed, it accommodates a huge increase in urban population within relatively small land areas, saving extra land resources, aligningwith land-use plans and facilitating service and infrastructural delivery. If managed proactively, urban population growth presents a huge opportunity to shift the structure and location of economic activity from rural agriculture to the larger, more diversified urban industrial and service sectors and creates larger markets for those who continue to engage in agriculture. On the other hand, if urbanization is poorly managed, it generates challenges such as informal settlements, poverty and poor waste management. A sub-optimal approach to urbanization creates stress on urban land and is detrimental to the well-being of the population. If not managed proactively, rapid urban population growth may pose a demographic challenge as cities struggle to provide jobs, infrastructure and services, and housing (World Bank Group, 2015).

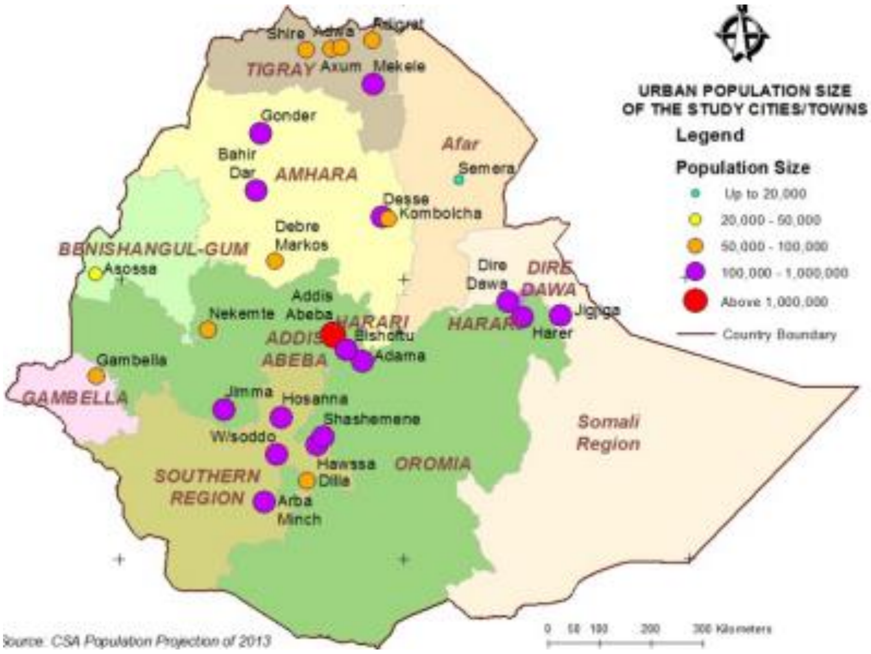


Figure 1. Population Size of Various Cities in Ethiopia (World Bank Group, 2015)

One of the Ethiopian government's most pressing challenges is to manage urbanization so that it allows for, and contributes to, inclusive growth, and in particular enables cities to adequately provide the services needed to ensure a better quality of urban life to the full spectrum of urban residents.

To understand more clearly urbanization in Ethiopia and the effect it may have on urban resilience and energy provision, trends in population growth and urban expansion, poverty and urban characteristics, and spatial distribution must be explored.

1.2.1. Population growth and urban expansion in Ethiopia

"Eastern Africa is the world's least urbanized but fastest urbanizing sub-region. By the end of the current decade its urban population will have increased by 50 per cent and the total number of urban dwellers in 2040 is expected to be five times that of 2010. It follows, therefore, that Eastern Africa will face huge challenges associated with massive urban population increases; [and] monumental new and additional demands for the provision of adequate and affordable housing and urban services" (UN Habitat , 2014).

Like much of East Africa, Ethiopia today is undergoing a fundamental spatial transformation. With an official population figure of 86.6 million people, Ethiopia ranks as the 14th most populated country in the world. Historically one of the least urbanized countries in sub-Saharan Africa (SSA), even within the African context, Ethiopia had an estimated 11 per cent of the total population living in cities in the early 1980s. This reality was partly the result of the country's historic emphasis on agricultural self-sufficiency, which reinforced rural activities (UN Habitat , 2014) (Schmidt & Mekamu, 2009) (Dijk & Fransen, 2008).

It is estimated that approximately 20 per cent of the total population of Ethiopia currently lives in urban areas. Even with this change, it is still one of the least urbanized countries in sub-Saharan Africa. Despite this low overall level of urbanization, the country has one of the highest rates of urbanization among all developing countries, estimated by the Ministry of Urban Development, Housing, and Construction (MUDHCO) at 4.1 per cent per annum (MUDHCO, 2014). This is also higher than the average growth rate of the total national population, which is estimated at 3 per cent per annum (MUDHCO, 2014).

With this rapid rate of urbanization, Ethiopia's urban population has doubled over the past 35 years, from 8.5 per cent of the nation's total population in 1967 to 17.4 per cent in 2012. Moreover, it is projected that by 2030 approximately 30 per cent of Ethiopians will live in urban areas, placing pressure on urban systems and services (DfID, 2015) (Cities Alliance, 2015). This unprecedented growth is a function of rural-urban migration, urban-urban migration in response to population-resource imbalances, urban expansion and land conversion, and natural population growth within cities (Hailemariam & Adugna, 2011) (Gebregziabher, et al., 2014).

Ethiopia's urbanization is characterized by increasing land coverage of residential areas. This type of urban expansion calls for an increase in urban infrastructure services that cater to residential users (that is, energy for cooking, heating, lighting, and water and sanitation). This has implications for energy usage in growing cities, because the infrastructure and energy needs of residential land use are different from the infrastructure and energy needs of commercial or industrial land use or activity.

Urban expansion in Ethiopia is also characterized by the absence of, or weak manifestation of, land-use control. This means that settlements are spreading into fringe farmlands with limited urban planning and coordination. This trend has been enabled by the process of legal expropriation of agricultural land by the state to use for residential purposes or to lease to private actors and investors for commercial or industrial purposes. It is noted that expropriated and duly compensated lands are made available as new settlement zones for development. Unfortunately, reports indicate that the land conversion process to meet population demands is slow, and the volume of supply compared to the demand is inadequate (Gebregziabher, et al., 2014).

The literature supports the notion that Ethiopia's rapid urbanization and population have outpaced the country's ability to create jobs. In the meantime, it is noted that Ethiopia's private sector, which is concentrated within and around Addis Ababa, is largely informal (African Development Bank Group, 2011). Further, the private sector firms face constraints such as a complicated land-tenure system, a burdensome tax system and limited access to finance (African Development Bank Group, 2011). Urban growth, particularly the movement of residential and commercial land use to rural areas at the periphery of metropolitan areas, has long been considered a sign of regional economic vitality. However, its importance has become unbalanced, with attendant impacts on the ecosystem, greater economic differences and social fragmentation.

While urban growth and its impacts are relatively studied in large and megacities (that is, a metropolitan area of more than 10 million people) worldwide, urban growth and modelling studies in cities of developing countries like Ethiopia are limited. Deforestation and land degradation are underlying major environmental issues in the SSA region, particularly in Ethiopia. Because of rapid urbanization, Ethiopia is a country characterized by swift environmental conversions and modifications attributed to human actions, such as the expansion of farm plots at the expense of natural lands, massive fuelwood and charcoal production, and overgrazing and encroachment of farmsteads into natural lands. Hence, a systematic analysis of land-use and land-cover change is crucial to comprehend the extent of the change and take necessary measures to scale down the rate of changes and protect the natural land cover resources sustainably (Tefera, 2011). Most land-cover studies in Ethiopia focus on the conversion of natural to support agricultural growth. Studies that explore the conversion of natural or agricultural lands to support population growth have limited data regarding the relationships among differentland uses such as residential, commercial or industrial land. From most of these studies it is evident that population pressure is one of the major drivers of land-use and land-cover changes through destruction of forest and vegetation cover for agricultural and urban expansion (Tefera, 2011) (Gebregziabher, et al., 2014).

At the national level, this type of urban expansion represents a challenge to meeting Ethiopia’s economic growth objectives; an increase in urban population and residential areas within the urban setting, without a commensurate increase in service delivery and provision, exacerbates poverty and unemployment and leads to a less resilient urban future. The effects are further amplified when urban residential growth far outpaces urban commercial and industrial growth in Ethiopia, because commercial and industrial activities represent productive opportunities while the residential sector is typically a consumer base.

1.2.2. Urbanization of poverty and "villagization" of the city

Individuals and groups moving from rural areas to cities often do so in search of productive activities and economic opportunity (Schmidt & Mekamu, 2009). However, in Ethiopia's case the historical rural-urban shift is unfortunately not correlated with a reduction in poverty. To the contrary, available evidence demonstrates growing limitations in access to services in urban areas, and the pace of urbanization has been faster than the increase in service delivery. People who move to cities may in fact face greater poverty than before.

There is evidence that vast regions within urban areas do not provide the amenities associated with urban life, leading to the description of the "villagization of the city." While populations may be living in or close to urban centres, everyday life of many remains similar to life in a rural context. For example, cooking is still predominantly undertaken using mechanical methods (using solid biomass fuels), and electricity is used primarily for lighting but not for additional modern amenities and conveniences associated with urban living. This observation is supported by the 2014 Ethiopia Urbanization Review, carried out by the World Bank, which notes that urbanization is failing to meet the demands of growing numbers of urban residents in three key areas: access to jobs, infrastructure and services, and housing.

Noting the above, the scale of urbanization being experienced in Ethiopia comes with a host of challenges, including growth in urban poverty and inequality. In fact, the Ethiopian government acknowledges that approximately 60 per cent of urban areas are estimated to be impoverished zones, devoid of basic services. Furthermore, urban unemployment is estimated at 16 per cent, and the percentage of urban dwellers living below the poverty line is nearly 25 per cent (MUDHCO, 2014).

1.2.3. Uneven population distribution

The urbanization trends discussed above are relevant to all cities and urban areas in Ethiopia. However, the recent State of Ethiopian Cities Report (World Bank Group, 2015) argues that these characteristics are of particular relevance to secondary cities, where resources are more limited, administrative capacity weaker, and migrants arrive directly from rural areas without many assets and skills to help them in the urban economy (MUDHC, 2014).

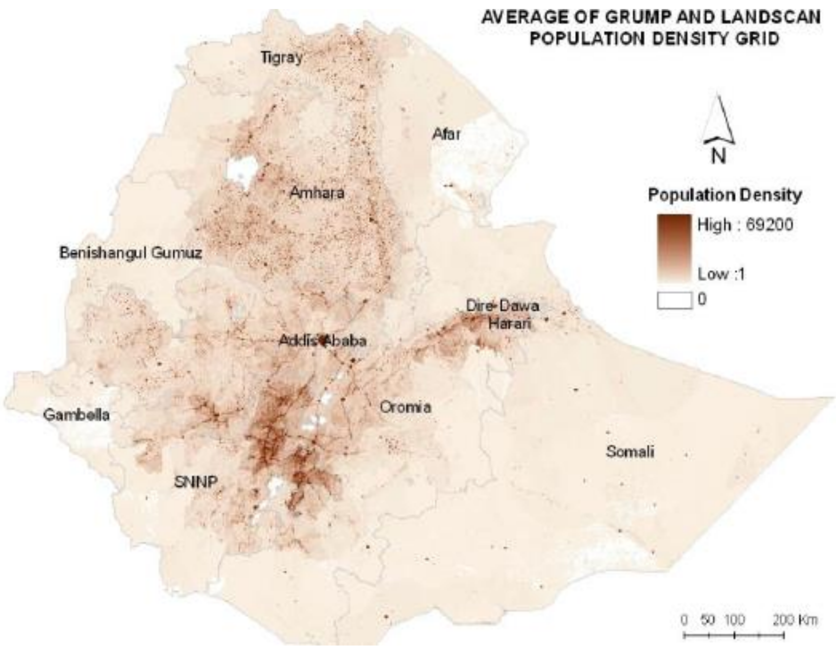


Figure 2. Ethiopia: Population Density Map (Schmidt & Mekamu, 2009)

Secondary cities in Ethiopia are significant because, while Addis Abba as a primate city has the highest number of inhabitants, the secondary cities are home to the majority of the country's urban population. Most of Ethiopia's urban growth is expected to be in the very same smaller, secondary cities that are already unable to meet demands for service provision. The population density map below illustrates population dispersal in Ethiopia as well as existing population hubs, mirroring the city distribution as illustrated in Figure 2 above.

1.2.4. The response to urbanization trends

Ethiopia's MUDHCO argues that urbanization should be met with the creation of a more dynamic non-agricultural economy. The government views cities and urbanization as opportunities to provide services more cheaply, and through this provide a link or act as an enabler for poverty reduction (MUDHC, 2014). To take advantage of the efficiencies inherent in urban settings, Ethiopia has actively considered facilitating an increase in economic density and creating networks of small towns and urban centres that could increase demand for rural goods and labour by urban populations (Schmidt & Mekamu, 2009).

Further it is noted that a region where agricultural productivity quickly increases is often one of the most rapidly growing urban centres, resulting from the need to provide agricultural produce to sustain these urban populations (Schmidt & Mekamu, 2009). Despite such intentions, however, Ethiopia still lacks a sufficiently large urban (that is, non-farming) population to generate enough demand for its own agricultural products, because of the proportion of current rural to urban dwellers; in excess of 70 per cent of the population is characterized as rural, resulting in rural supply potentially exceeding urban demand (Schmidt & Mekamu, 2009) (DfID, 2015) (Cities Alliance, 2015). Much of the urban economic theory suggests that urbanization emerges from the transformation of agriculture and is a spatial implication of economic transformation. However, the flip side of this is that agricultural growth is constrained by inadequate demand. This has led some to argue that many of Ethiopia's development problems are, in fact, the result of the low percentage of urban population and, therefore, the low demand for agricultural supplies (World Bank Group, 2015).

Thus, from an economic productivity and market-creation point of view, there appears to be ample room for expanded urbanization in Ethiopia to accelerate economic growth (Schmidt & Mekamu, 2009). However, what is also clear is that urbanization has already increased faster than services can be adequately provided, especially in smaller and secondary cities. This creates a dilemma for Ethiopia as it seeks to manage its urbanization.

From an energy services delivery lens, this is a conundrum. On the one hand, urban density allows for more efficiencies in electricity service provision (including lower per-capita costs of transmission and so on); on the other hand, electricity access is already strained in several urban areas, and it will be a challenge for it to keep pace with urban growth.

1.3. The significance of secondary cities

Secondary cities can be described through their role relative to larger cities (John, 2012). UN-Habitat defines a "secondary city" as an urban area generally having a population of between 100,000 and 500,000 (Roberts, 2014). However, an alternate definition suggests that secondary cities are those that have populations ranging between 10 per cent and 50 per cent of a country's largest city. Most have populations between 100,000 and 5 million, depending on the size of the country, although a few are smaller or larger than this. Roberts (2014) suggests three secondary city typologies: first, secondary cities include sub-national urban centers characterized by administration, manufacturing or agricultural activities; second, these cities can develop as metropolitan-clustered secondary cities that develop on the periphery of metropolitan or urban regions and take the form of new towns, serving as spill-over growth centers; and third, corridor secondary cities, which develop as growth poles along major transportation corridors.

As a testament to the growing importance of secondary cities, the United Nations' State of African Cities Report 2014 advised that governments should urgently reduce the land, housing, services and mobility-demand pressures on their primary and capital cities by seeking more balanced national urban hierarchies, with the emphasis shifting to secondary cities. The report recommended that population pressures be addressed through population dispersal by the establishment of satellite cities and growth corridors to manage spatial growth (UN Habitat, 2014).

The hierarchy of cities in Ethiopia is dominated by Addis, which, as mentioned earlier in this chapter, is a “primate” city. This means that it is the leading city in the country or region, and is disproportionately larger than others, in this case at least five times bigger than the only other chartered city, Diré Dawa. The result is a focus of government spending and planning efforts on managing the growth of the primate city, over that of smaller cities. While the capital accounts for 25 per cent of Ethiopia’s urban population, secondary cities are growing as well, with smaller towns and secondary cities housing approximately 75 per cent of the urban population (UN Habitat, 2014) (Schmidt & Mekamu, 2009).

1.4. Secondary city case studies

In terms of national planning and strategies, since the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) was adopted, and together with the Growth and Transformation Plan (GTP), it has placed more emphasis on the importance of urban development within Ethiopia. This is an important conceptual shift from a focus on rural considerations that acknowledges the significance of urbanization and the future role of cities as engines for economic growth. It is within this context of institutional recognition of increasing urbanization that secondary cities become important nodes for stimulating economic growth through both investment and poverty alleviation initiatives.

As described in the Methodology Section, two secondary cities were selected for this study, Diré Dawa and Mekelle (their locations are illustrated in Figure 3).

Figure 3. Location of Two Study Areas: Mekelle and Diré Dawa (illustrated by arrows) (Lonely Planet, 2016)

Spatial urban demand varies across Ethiopia, as would be expected because of the specificity of the different drivers and constraints of urbanization as described earlier. (The New Climate Economy, 2015) illustrated a composite projection of Ethiopia's spatial urban demand. The highest urban demand can be seen around the current urban centres of Diré Dawa, Bahir Dar, Gondar and Mekelle, with significant demand also around Dessie, Adama, Hawassa and Jimma. Considering the government's planned secondary cities, this reinforces the choices made in selecting these urban growth areas (The New Climate Economy, 2015). One potential point of investigation in a future research agenda would be to examine why southern and southern-eastern parts of Ethiopia exhibit lower urban demand (although this is very likely the result of availability of and access to natural resources, which is considerably lower in the arid Horn of Africa region in the east). Lower demand would also imply diminished industrial activities in these regions because of a smaller natural resource base.

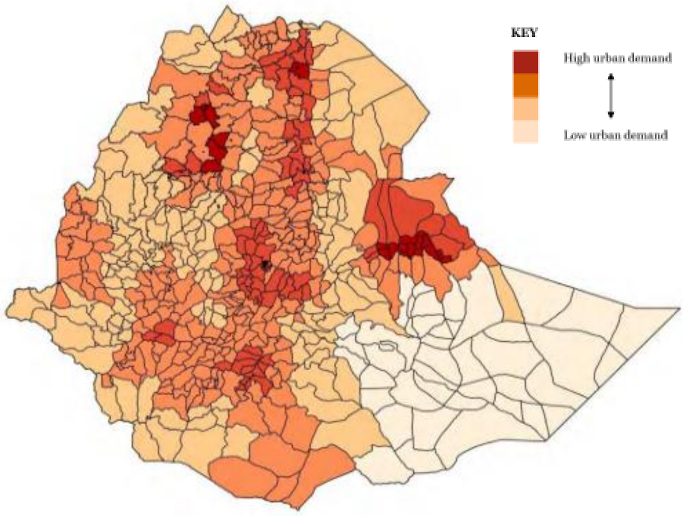


Figure 4. A composite projection of Ethiopia's Urban Demand (The New Climate Economy, 2015)

Chapter 6 provides high-level summaries of the current socio-economic and urban status quo in Diré Dawa and Mekelle, exploring socio-economic trends underpinning urbanization and future demand for urban services including jobs, infrastructure and services, and housing.

1.5. Institutional context of cities in Ethiopia

The following review of the institutional context in Ethiopia provides a discussion of both the institutional governance structures and the institutional approach to land management within Ethiopia.

1.5.1. Institutional arrangements and governance

From a governance perspective, Ethiopia is a federal state with a decentralized form of government, as established in the 1994 Constitution. The political history of Ethiopia was dominated by highly centralized rule until the transition into decentralized governance in 1991. Since 1996, Ethiopia's governmental system has consisted of a federal government overseeing nine ethnically based regional state governments, each with its own constitution, and two city administrations known as "charter cities," namely, Addis Ababa and Diré Dawa. Regional governments are composed of a multitude of districts called woredas. There are about 770 woredas in the country (670 rural and approximately 100 urban). Woredas are themselves composed of a number of kebele (wards, neighbourhood associations), which are the smallest unit of government; the 11 woredas are typically combined into districts and function as semi-autonomous entities. In terms of infrastructure development to support service-delivery, the national government remains the responsible actor despite the decentralized model (DfID, 2015) (Gebregziabher, et al., 2014).

"City proclamations" are the legislative tools used, and regional states have enacted city proclamations that make possible the establishment of local urban governments with increased financial and administrative autonomy. As per these regional city proclamations, urban local governments are primarily accountable to their city councils. However, it is reported that regional governments exert considerable influence and control on the local affairs of cities. This is possibly because of the recent devolution process, meaning that Ethiopian cities have a relatively short history and limited experience of self-government. The result is that these cities are confronted with enormous governance and service delivery challenges accompanying their rapid population growth. Further, national and regional entities remain responsible for several services (that is, electricity, national roads and public transport) that influence city government decision-making and urban planning (DfID, 2015). The location of electricity, or energy provision, at the national level is significant to this study.

1.5.2. Institutional approach to urban planning

Despite these challenges, the country sees huge social, economic and political growth potential in urbanization and has therefore developed a comprehensive urban development strategy championed by the MUDHCO, as well as by regional governments and cities. A number of policy and legal frameworks have been instituted to support urbanization: Capacity Building for Decentralized Service Delivery (CBDSD), the Public-Sector Capacity Building Programme (PSCAP), and the Urban Local Government Development Programme (ULGDP) are examples of the large-scale programmatic public-sector interventions in urban development in Ethiopia.

Because of this approach, two main planning processes occur within an Ethiopian city: first, the creation of the city-wide master plan, and second, the creation of local development plans at the sub-city level. Both are informed by the national urban development scheme, and the local development plans are the implementation plans of the master plan. These plans have influence, and considerable effort is placed into developing them and using them to guide local development initiatives (DfID, 2015).

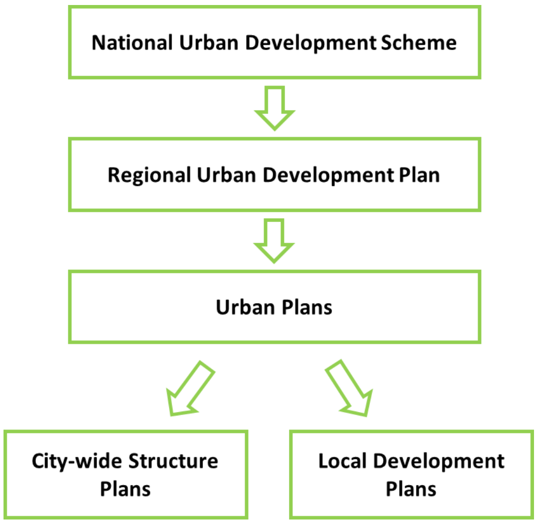


Figure 5. Hierarchy of spatial plans in Ethiopia

2. A changing climate and the need for climate-resilient energy supply

This chapter introduces the climatic profile of Ethiopia, prevalent climate systems, and the types of temperature and rainfall regimes they produce. Observed and projected trends linked to climate change are described, particularly in the central and northeastern parts of the country where Dire Dawa and Mekelle are situated. The resultant climate vulnerabilities and climate-induced stresses are noted, including a range of expected social, environmental and economic impacts. Particular attention is drawn to climate variability and climate change impacts on energy resources such as bio-energy and hydroelectricity. As secondary cities are the axes of growth in population and the economy, countrywide climate vulnerabilities and energy security issues are particularly pertinent for these cities.

2.1. Climate patterns and climate change

2.1.1. Current climate

Ethiopia's climate is typically tropical in the southeastern and northeastern lowland regions, but much cooler in the large central highland regions of the country. Mean annual temperatures are around 15-20 °C in these high-altitude regions, whereas they are 25-30 °C in the lowlands (McSweeney, et al., 2010). Rainfall regimes also vary across regions. Mean annual rainfall ranges from less than 300 mm in the southeastern and northwestern lowlands to more than 2,000 mm in the southwestern highlands (Regassa, 2010).

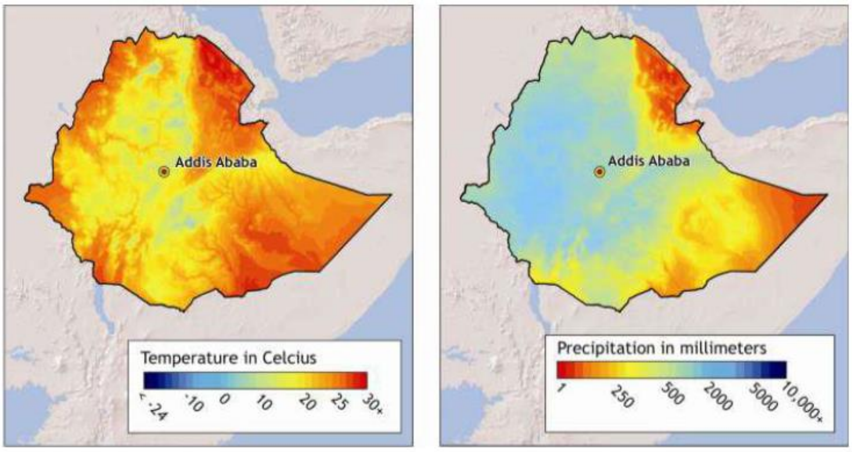


Figure 6. Current climate: mean annual temperature (left) and total annual precipitation (right) (NCEA, 2015)

The rainfall seasons in Ethiopia vary across the country. "Kirmet" rains (from June through September) constitute the primary rainy season for most parts of the country except in certain areas of the south and southeast, where the "Belg" rains (March through May) make up the main rainy season. Thus, rainfall in Ethiopia is characterized by a bi-modal seasonal cycle, with rains in June through September and again in March through May. The south and southeastern parts of the country are somewhat distinct from this bi-modal pattern; these regions receive very short rains during the period September through November, which is typically the dry season for the rest of the country (Abede, 2010).

The rains in Ethiopia are influenced by different global and regional rain-bearing factors. The main features that affect the Kirmet rain include the Inter-Tropical Convergence Zone (ITCZ), Tropical Easterly Jet (TEJ), South Atlantic Ocean and South West Indian Ocean anticyclone, East African Low Level Jet (EALLJ) or Somali Jet, and the El Niño Southern Oscillation (ENSO). Global and regional weather features that affect the Belg rain include the ITCZ, Subtropical Westerly Jet (SWJ) stream, Arabian High pressure, the frequency of tropical cyclones over the Southwest Indian Ocean, and ENSO (Abede, 2010).

The movements of the ITCZ are sensitive to variations of Indian Ocean sea-surface temperatures and vary from year to year. Hence, the onset and duration of rainfall seasons vary considerably, catalysing frequent drought. The strong inter-annual and inter-decadal variability in Ethiopia's rainfall makes it difficult to detect long-term trends (McSweeney, et al., 2010). At a national level, rainfall in Ethiopia is highly variable in both inter-annual and inter-decadal terms, and the country has experienced both dry and wet periods over the past four decades.

As described above, the rainfall regime in Ethiopia is characterized as uni-modal in the majority of the country, and bi-modal in the south and southeast. The country is influenced by topographical variation, seasonal cycles and opposing responses to regional and global weather systems; consequently, three rainfall regimes are commonly identified (as illustrated in the figure on the right) (Abede, 2010).

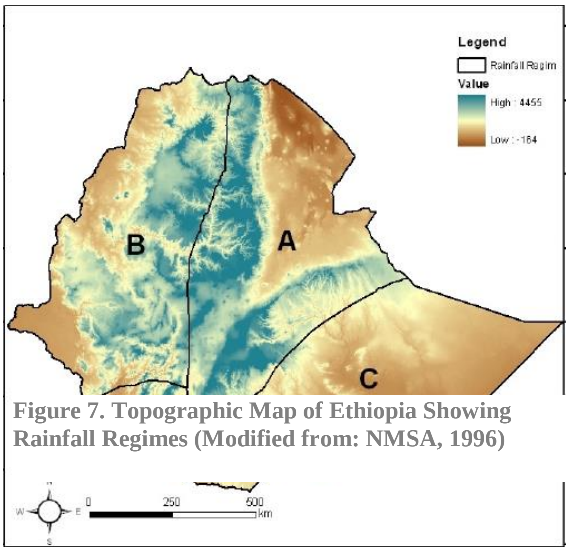


Figure 7. Topographic Map of Ethiopia Showing Rainfall Regimes (Modified from: NMSA, 1996)

Both the case study cities are in Regime A, which comprises the central and the northeastern part of the country. The region has bi-modal rain; that is, rain falls during the long rainy season (June-September) and the short rainy season (March-May), locally referred to as Belg and Kiremt rains, respectively. The rest of the months (October-February) are a dry period in this regime area (Abede, 2010).

There has been an increase in seasonal mean temperature in many areas of Ethiopia over the last 50 years (Funk, et al., 2008). For the past four decades, the average annual temperature in Ethiopia has been increasing by 0.37 ºC per decade, with most warming occurring during the second half of the 1990s (EEA, 2008). Other studies of national climate trends since the 1960s show that mean annual temperatures in Ethiopia have increased by between 0.5 °C and 1.3 °C (ACCRA, 2012). In addition, the frequency of cold nights (linked to frost in dry season) has decreased significantly in all seasons (McSweeney, et al., 2010). Although national models and missing data obscure regional differences in variability and trends, there is evidence of a declining trend in the February-April short rains between 1981 and 2000, and slight increases in the June-August long rains, as well as in October and November over the same period (Conway, et al., 2007). A different study indicates that between the mid-1970s and late 2000s, Belg and Kiremt rainfall decreased-Ethiopia (USGS, 2012).

Given the dependence on rain-fed agriculture, these trends could have a negative impact on food security (Funk, et al., 2005). The decrease in precipitation has multiple effects on agricultural production and water availability for irrigation and other farming uses, especially in the north, northeastern and eastern lowlands of the country (Aragie, 2013).

Extreme events are common in Ethiopia, especially droughts. Ethiopia has been ranked 5th out of 184 countries in terms of its risk of drought (Swarup, et al., 2011). Between 1900 and 2010, 12 extreme droughts were recorded (killing more than 400,000 people and affecting more than 54 million) (You & Ringler, 2010); 7 of these have occurred since 1980 (World Bank, 2010). The majority of these resulted in famines. Apart from these major or extreme droughts, there have been dozens of local droughts with equally devastating effects (NCEA, 2015). Ethiopia is during its worst drought in 50 years, exacerbated by a particularly strong El Niño.

At the same time, flood events are also reported as more common, with significant disruptions from flooding occurring in 1997 and 2006 (Conway, et al., 2007). The country has experienced even more major floods in different parts of the country, though with fewer people affected: 47 major floods since 1900 (of which 6 occurred since 1980) killed almost 2,000 people and affected 2.2 million (You & Ringler, 2010). Ethiopia ranked 34th out of 162 countries in terms of flooding risk, and 5th out of 162 in terms of landslide risk (Swarup, et al., 2011)

Changes in temperature and rainfall increase the frequency and severity of extreme events. Warming has exacerbated droughts, and desertification in the lowlands of the country is expanding. The increase in severity of short, heavy rains in the highlands leads to increased flooding in the lowlands, causing further soil degradation in already exposed areas (Eshetu, et al., 2014).

2.1.2. Climate projections

Climate change projections are subject to uncertainties and data gaps and can be contradictory. In Ethiopian climate models, there are high levels of confidence in projecting continuing temperature increases, though the extent of the rises depends on emissions scenarios and varies among models (ACCRA, 2012). A review of 18 different models and emissions forecasts predicted warming of 1.2 °C by the 2020s in all four seasons in all regions of Ethiopia (Conway, et al., 2007) from 1961-2000 mean temperatures. Another study predicts that temperatures could increase by between 1.5 °C and 5.1 °C by 2090, (from the 1970-1999 mean) depending on the levels of emissions reductions and range given in the models (McSweeney, et al., 2008)

Future temperature projections of the IPCC mid-range scenario show that the mean annual temperature will increase in the range of 0.9-1.1 ºC by 2030, in the range of 1.7 ºC-2.1 ºC by 2050, and in the range of 2.7 ºC-3.4 ºC by 2080 in Ethiopia compared to the 1961-1990 norm (EEA, 2008), posing a sustained threat to the economy. McSweeney et al. (2010) suggest even higher temperature ranges: a projected rise of 1.1 °C-3.1 °C by the 2060s, and of 1.5 °C- 5.1 °C by the 2090s.

While all models foresee warming, they contradict each other as to where the largest increase will happen: in the west and north, in the northwest, the northeast and central areas (Admassu, et al., 2013), or in the south-central part. Most models indicate substantial increases in the frequency of hot days and nights, with up to 93 per cent of days and 99 per cent of nights considered “hot” in the July-September season by the 2090s (compared to 10 per cent of days and nights in the same season in the 1960s) (McSweeney, et al., 2008).

There is less confidence in rainfall projections and less convergence among models. A slight increase in average annual rainfall is projected nationally, but with seasonal and regional differences, which may mean some regions might experience decreasing rainfall in certain seasons (Conway, et al., 2011). The models broadly agree that more rain will fall in “heavy events,” in increased volumes over shorter periods of time (McSweeney, et al., 2008).

According to EEA (2008), IPCC forecasts on levels of precipitation in Ethiopia show a long-term increase in rainfall, despite the short- and medium-term observation of frequent dry periods interspersed with heavy and intense rainfall levels. The average change in rainfall is projected to be in the range of 1.4- per cent-4.5 per cent, 3.1 per cent-8.4 per cent, and 5.1 per cent-13.8 per cent over 20, 30, and 50 years, respectively, compared to the 1961 to 1990 normal (Aragie, 2013).

Despite current trends of rainfall decreases, in the long-term precipitation for Ethiopia as a whole is projected to increase by about 9 per cent over 50 years (compared to 1975) (Aragie, 2013). Higher-resolution analyses, however, show both increases and decreases in different parts of the country. Even on a more local scale, there can be large differences: A study on different districts in the Central Rift Valley projected rainfall decreases of over 11 per cent for some, and increases of almost 9 per cent for other, relatively nearby, districts (Gizachew & Shimelis, 2014). An increase in rainfall variability is predicted for the whole country, making rainfall less predictable. Moreover, a larger share of total precipitation will fall during heavy precipitation events, especially from July to December (Eshetu, et al., 2014). This is expected to lead to increased incidence of extreme events, with severe droughts in one year, and heavy flooding with erosion and landslides in the next (Aragie, 2013).

When considering ranges of projected changes, it is important to note that the average does not imply a greater likelihood of occurrence; there is still great uncertainty in climate projections. The full range of projected changes must be accounted for when considering impacts and adaptation; the greater the temperature increases, the more severe the impacts are likely to be. For Ethiopia, even the projected temperature changes under the most modest emissions increase scenarios (that is, scenarios with the most ambitious emissions reduction assumptions) will have significant impacts for agriculture, extreme events and the livelihoods of many (Trocaire, 2014).

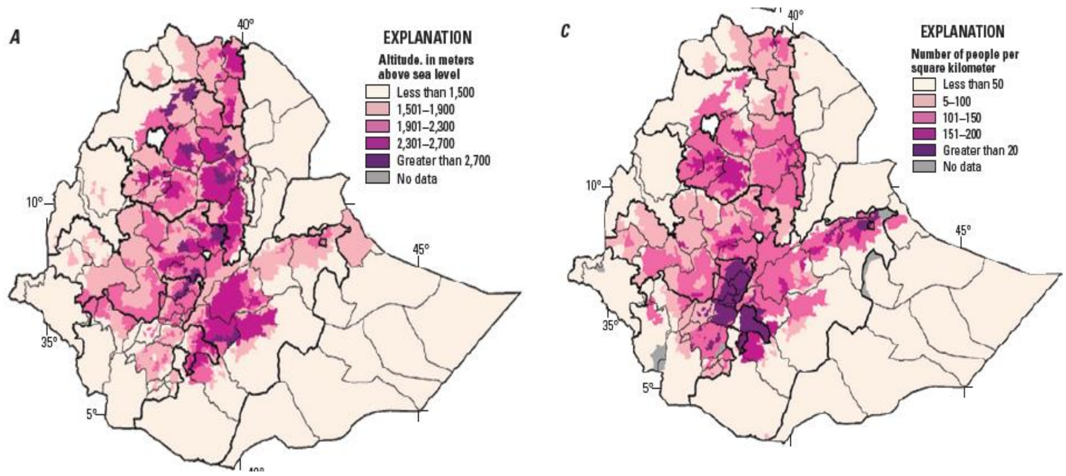
A further complication in projecting climate impacts is that Ethiopia's exposure to drought and floods is heavily influenced by the El Niño/La Niña phenomena, and the impacts of climate change on these phenomena are not yet clear (Christensen, et al., 2007). However, recent science based on climate models indicates that global warming is exacerbating the effect of the ENSO cycles, resulting in climate extremes under each phase. Therefore, viewing the ENSO as a purely weather-related event that is not influenced by climate change will not consider the likelihood (and eventuality) of climate extremes. In addition, as the ENSO influences climate-related aspects such as sea surface temperatures (SSTs) and atmospheric circulation, changes in the ENSO will result in changes in related climate mechanisms.

2.2. Climate variability, climate change and society

Ethiopia is faced with increasingly unpredictable rains, and sometimes the complete failure of seasonal rains, problems that are both linked to climate change. It is a country with large differences across regions that are reflected in the country's climate vulnerability (NCEA, 2015). Ethiopia is a large, complex country, with complex patterns of rainfall and livelihoods (USGS, 2012).

Higher elevations (as illustrated in Figure 8) receive more rainfall than low arid areas and support agricultural livelihoods and higher population densities. Lowlands receive minimal rainfall, and people generally support themselves by raising livestock. In between, agro-pastoralists rely on a mixture of the two livelihood strategies. The population density of Ethiopia varies dramatically (USGS, 2012), from more than 300 people per square kilometer (km^2) in some parts of the Southern Nations, Nationalities, and Peoples Region (SNNPR), to less than 10 people per km^2 in areas dominated by pastoral livelihoods. Most rural people live in the highlands and middle-highlands, which make up only one-third of the country, and this population tends to be concentrated primarily in Oromia or northern SNNPR (USGS, 2012).

Figure 8. Elevation and population density based on the 2007 National Population Census (USGS, 2012)



In Ethiopia, population density is highest in parts of the SNNPR and lowest in pastoral livelihoods areas. The purple areas in all panels highlight high population densities; many of these most densely populated areas are affected by the March–June, June–September, or

March–September rainfall declines. The correspondence between the high population densities in the south-central Rift Valley area and the receding long-cycle (March–September) rainfall pattern is of particular concern. This area is heavily populated, all available fertile land has been cultivated, and the size of land holdings is diminishing as population grows. It appears likely that the combination of population growth, land degradation, and more frequent droughts will result in more frequent food-related crises (USGS, 2012).

The lowlands are vulnerable to increased temperatures and prolonged droughts that may affect livestock rearing. The highlands may suffer from more intense and irregular rainfall, leading to erosion, which together with higher temperatures leads to lower total agricultural production. This, combined with an increasing population, may lead to greater food insecurity in some areas. High and increasing population density increases climate change vulnerability, as it decreases the amount of resources (including water and food) available per person and may lead to resource conflicts.

Figure 9 shows the projected change in population density that can be attributed to (migration related to) climate change, indicating the highest increase for already densely populated areas. Hotspots of increased food insecurity in the future, the result of climate change, are likely to include areas in Afar and Tigray, southern Oromia, the central Rift Valley, and the eastern lowlands (NCEA, 2015).

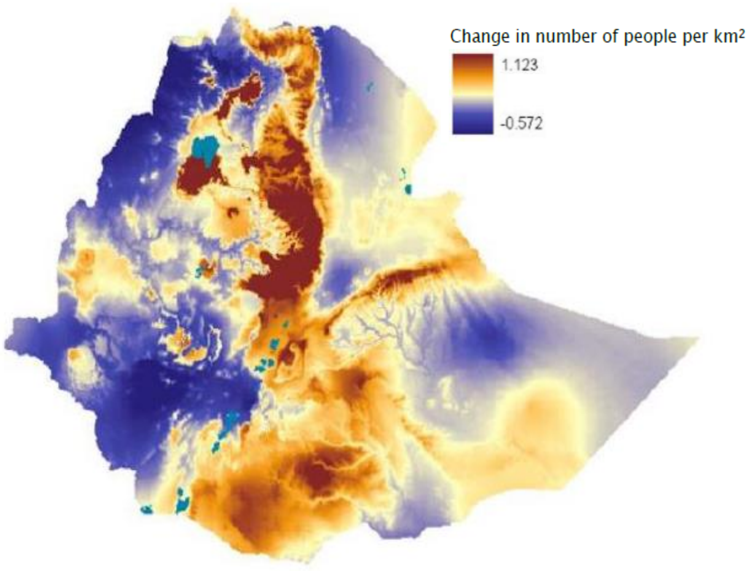


Figure 9. Changing population density in response to climate change (2005-2050 (Hopping and Wann, 2009 in NCEA, 2015)

Given that Ethiopia is a land-locked country dependent on agricultural, agro-pastoral and pastoral livelihoods, this population expansion will place increasing stress on limited natural resources (USGS, 2012). While the economic and social impacts of climate change at the national level are difficult to estimate, the World Bank's study of the Economics of Adaptation to Climate Change indicated that climate change had the potential to reduce Ethiopia's GDP growth by 2 per cent-6 per cent by 2015, with losses in the worst-case scenario rising to 10 per cent by 2045 (World Bank, 2010).

The sectors in which economic effects of climate change will be most felt are agriculture, roads and hydropower infrastructure (World Bank, 2010). Agriculture is Ethiopia's dominant sector, contributing around 50 per cent of its GDP. It is the main source of food for its population (Gizachew & Shimelis, 2014), but also contributes 90 per cent of its exports and serves as the main source of inputs for the country's industrial sector (Aragie, 2013). The sector is also important in terms of employment; about 85 per cent of the population is in some way employed in agriculture (full- or part-time on own farms, or as day labourers) (Admassu, et al., 2013).

Despite the multi-faceted impact of climate change in Ethiopia, it is possible to develop a rough estimate of the past and short-run effects of climate change on growth and poverty by concentrating on its impact on agriculture. First, agriculture is by far the dominant producer and employer, and the main source of foreign currency. Second, structurally, the agricultural sector is highly susceptible to the causalities of climate change. Third, the agricultural population constitutes the significant majority of the Ethiopian poor and highly vulnerable people. Although agricultural failure can harm the rural poor, it can also have a significant impact on the urban poor, by affecting availability and access to food. The urban poor are affected in terms of high food prices, limited job opportunities in the agro-processing industries, and expensive imported food items resulting from foreign exchange shortages (Aragie, 2013).

Smallholder farmers are overall the most vulnerable groups to climate change; others are the rural landless, the urban poor in flood-prone areas, the elderly and sick, and women and children left behind as male adults migrate for employment. A factor of specific importance in climate change vulnerability is gender. In poor areas, women often have more household responsibilities (25 per cent of small, poor farm households were identified as female-headed in some Ethiopian districts, compared to only 5 per cent-7 per cent of other households). They are often disproportionately affected by climate change impacts, as they are typically the ones whose primary responsibilities include the collection of water for drinking, cooking and washing; the collection of fuelwood; and the small-scale cultivation of subsistence crops. An additional (indirect) effect of climate change is that women and girls have been found to be more vulnerable to sexual abuse because they must travel to more remote sources of water (Swarup et al., 2011). The ability of women and girls to cope with the effects of climate change is often significantly lower than for men, because of their reduced access to information, markets, mobility, alternative income sources and decision-making mechanisms (NCEA, 2015).

The IPCC Fifth Assessment Report projects fluctuations and variability in precipitation and temperature over the coming century. In Ethiopia the variability of precipitation and temperature has serious implications for 85 per cent of rural Ethiopians who are dependent on rain-fed agricultural livelihoods (Tadege (eds.), 2007), with changes likely to affect productivity of certain crops, timing of agricultural practices and losses imposed by pests and diseases, all of which negatively affect food security (Trocaire, 2014).

Climate change has strong links with poverty and hunger. Not only does climate change increase poverty and hunger through its adverse effect on food security and economic development, poverty and hunger also decrease people’s resilience and ability to adapt to climate change effects. Ethiopia has historically been vulnerable to food insecurity. Food insecurity is highest in the east of the country or in parts of central Ethiopia, depending on the method used to measure it. Food insecurity is most pronounced before harvesting, when food stocks have finished. While most of the country has one season per year when the risk of food insecurity is high (June-September), the eastern pastoralist has two (February-April and September-October) (NCEA, 2015).

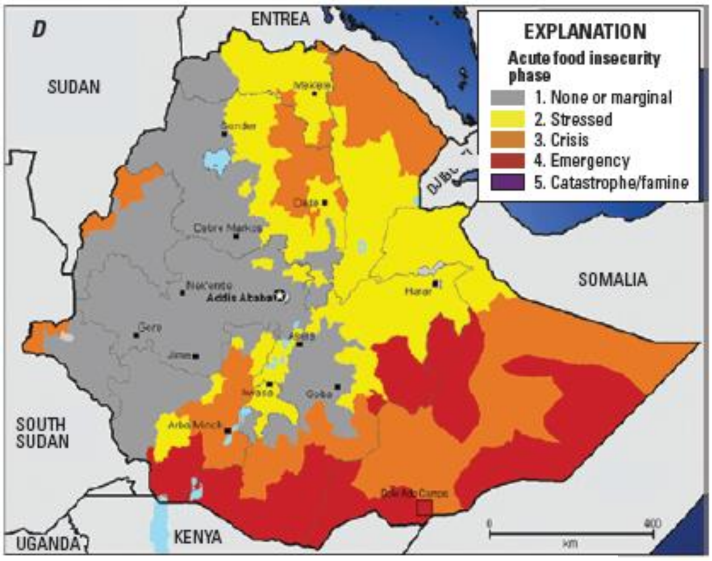


Figure 10. Food insecurity based on food availability (USGS, 2012)

Limited scientific information is available on the impact on health from current and future climate change in Ethiopia. Rising temperatures and increases in rainfall intensity may shift or extend the areas affected by vector-borne diseases. Increased occurrence of floods and heatwaves will also have implications for health, as will impacts on food production. As climate change may affect water quality and availability, this will have a significant impact on an already vulnerable population. Deaths from diarrheal diseases in Ethiopia are already significantly higher than in other East African countries (Cesar & Ekbom, 2013).

2.3. Climate variability, climate change, and energy

2.3.1. Climate variability, climate change impacts on energy resources

The main sources of energy in Ethiopia today are biomass and hydro-electricity. The current energy mix greatly increases the country's vulnerability to climate change. As climate change and variability affect Ethiopia, access to resources may deteriorate. Climate change may reduce productivity of forests, crops and livestock, which in turn reduces availability of fuel. Changing temperatures and water regimes could result in low productivity of vegetation and decreased access to biomass fuels. Therefore, the combination of constrained access to biomass and reduced availability of hydro-electric resources could result in an increase in the cost of electricity. In addition, a possible inconsistency of electricity supply also translates into a loss production of the manufacturing and services sector, which fuels the livelihoods and economies of cities.

2.3.1.1. Bio-energy

According to the IPCC, the future technical potential for bio-energy could be influenced by climate change through negative effects on biomass production such as altered soil conditions, precipitation, crop productivity and other factors. The overall impact of a global mean temperature change of less than 2 °C on the technical potential of bio-energy is expected to be relatively small on a global basis. However, considerable regional differences could be expected, and uncertainties are larger and more difficult to assess compared to other RE options because of the large number of feedback mechanisms involved (IPCC, 2011).

The reliance on fuelwood and charcoal in Ethiopia brings widespread land degradation, exposing bare soil to erosive rainfall and gulley erosion. As climate impacts increase, potentially reducing agricultural yields, there is likely to be a higher reliance on forest products for livelihoods, but further denudation and degradation are arising from this increased reliance, making climate change impacts such as heavy rainfall even more dangerous, as land degradation could exacerbate flooding. In the same vein, such degradation could reduce the rate of aquifer recharge, making the impacts of drought more intense or prolonged.

Ethiopia's energy crisis and vulnerability resulting from climate change are reflected in its overreliance on indigenously sourced biomass fuel. Guta (2012) assessed the biomass fuel resource potential of Ethiopia and investigated strategies for its modern utilization, emphasizing sourcing options for cleaner energies. The study focused on how the negative consequences of biomass fuel consumption on the livelihood of the poor in Ethiopia can be mitigated. A key outcome of this study was that innovative investment in renewable biomass-based fuels (such as, biogas, bioethanol and bio-diesel) and broad distribution of improved fuel stove technologies to rural and urban households, as well as energy conservation technologies for industries and the service sector should be promising areas for policies targeting green growth (Guta, 2012).

2.3.1.2. Hydroelectricity

With its extreme dependence on hydro-electricity as a source of power, Ethiopia is likely to face challenges in accelerating sustainable growth because of climate change. Ethiopia has already announced plans to significantly increase its hydro-electricity production to supply power to its neighbours and earn much-needed foreign exchange. While these plans do offer huge potential to support low-carbon growth in Ethiopia and the region, they need to carefully consider the implications of future climate change, so that benefits can be sustained despite anticipated changes.

One of the principal impacts of climate change in Ethiopia is changing rainfall patterns. Climate models project that total rainfall volumes will increase. However, projections also suggest a rise in variability of rainfall in terms of timing and duration. This increase in variability has implications for hydrological regimes of rivers. Given that approximately half of Ethiopia's hydropower potential is on the Abay River (the Blue Nile), climate change studies have paid particular attention to the river, or sub-basins within it, to assess what impacts climate change may bring. Several recent studies (Dile, 2013) (Worku FF et al., 2014) (Kim, 2014) indicate that river flows are likely to increase with climate change. With particular reference to hydropower, Kim et al. note in a report for the International Water Management Institute (IWMI) that climate change may even result in a rise during low-flow seasons, and that potential future dam operations on the Upper Blue Nile are unlikely to significantly affect the water availability for lower riparian countries (Egypt and Sudan). While there is some uncertainty in such models, the results suggest that Ethiopia will continue to have potential to produce hydropower (as well as increase its storage capacity) without affecting outflows to other countries in the mid-century timeframe. Dry season flows were found to increase even in the Omo-Ghibe Basin (an endorheic river basin, that is, one that does not drain into the sea or ocean but drains inland into lakes), according to climate models (Worku FF et al., 2014). However, other studies suggest some basins may face reduced flows, particularly in the dry season. One important factor for this is the higher evaporation caused by higher temperatures. A study by Trocaire, for instance, notes that the Gibe catchment in southwest Ethiopia may see reduced flows by mid-century, while even the Ganane and Nile basins may start seeing reduced flows towards the end of the century (Trocaire, 2014).

The variance in research findings is showcased in Taye et al. (2015), wherein the authors acknowledge the discrepancy between different studies and note that the widely divergent results for future hydrological flows are a result of using different climate models, different scenarios, and different down-scaling methods. They present a table that encapsulates this variation.

Table 1. Overview of selected future projections of high and low stream flows in the Blue Nile basin (Taye, 2015)

Climate projection	Hydrological variable	Basin (sub-basin)	Bias correction or downscaling method	Projection horizon and results	Reference
Six GCMs (A2)	Q_{90} Q_{10} Precipitation deficit of 6-months (SPI6)	Upper BNR divided into six sub-basins	Triangular cubic interpolation method	2050s Large increase in low streamflow statistic (Q_{90}) and wider range (−25%-60%) Slight increase in high streamflow statistic (Q_{10}) and narrower range (−15%-20%) Reduced severe drought events	Kim et al. (2008)
Three GCMs (A2, B2)	Q5 Q1	Upper BNR	Non-linear regression	2020s, 2050s, and 2080s Wide range of change for Q5 (−43%-32%)	Nawaz et al. (2010)
Five GCMs (RCP2.6, RP8.5)	Q_{90} Q_{10}	Upper BNR	Trend-preserving bias correction	2050s and 2080s An increase in high flows (Q_{10}) from 10%- 50 % An increase in low flows (Q_{90}) from 40%- 60%	Aich et al. (2014)
17 GCMs (A1B, B1)	Daily scale high and low streamflows for return periods between 1 and 10 years	Lake Tana sub-basin	Quantile perturbations	2050s Unclear projection consisting of both increasing and decreasing trends Based on average for all return periods, high stream flows change from −31%-79% and low streamflows change from −61%-56%	Taye et al. (2011)

Three GCMs (A2)	Q_{80}	Lake Tana sub-basin	Bias correction using the Water and Global Change (WATCH) Forcing Data	2040s and 2080s Results do not agree on the direction and magnitude of the drought characteristics	Enyew et al. (2014)
One GCM (A2, B2)	Q95 Q70	Gilgel Abay sub-basin	Multiple linear regression	2020s, 2050s, and 2080s No major effect for low flows of Q95 Decrease in Q70 during the 2020s and 2050s while increase in the 2080s	Dile et al. (2013)

The main takeaway from this analysis is that, while there is some convergence about increased river flows in the first half of the century, there is still a great deal of uncertainty, especially regarding low-season flows. Hydrological variability is a factor that the hydropower sector in Ethiopia must consider.

Demissie and Asfaw (forthcoming) examined the susceptibility of Ethiopian power systems to extreme hydrological conditions. The study found that the cost of electricity differed significantly based on different variables. Of particular concern are low inflow scenarios. The study found that the power system has very poor resilience against climate change. Since most projections suggest that climate change will spur extreme weather conditions in the future, it is important that policymakers and power system planners focus on transitioning the existing power system in Ethiopia to a system that is adaptive and can respond to negative impacts of hydrological variability.

Besides the cost of hydro-electricity in the face of climate change, other costs include disrupted economic productivity from interrupted power supplies. Ethiopia has already witnessed this, such as through the drying of Lake Alemaya; decreased water volumes in the lake and rivers connected to it precipitated serious seasonal electric power interruptions (Aragie, 2013).

In Ethiopia, reduced power production during drought years already takes a significant toll on the economy. In 2002-2003, power supply was lost one day a week over four months because of drought. It has been estimated that the loss of power caused a 10 per cent-15 per cent reduction in GDP generation. Between 2006 and 2008, Ethiopia experienced more than 6 months of power cuts because of low water levels in hydro-dams. Initially, blackouts were scheduled for once a week, but as the drought wore on, customers lost power for 15 hours daily, for 2 days a week (Karekezi, et al., 2009).

A study by the Energy, Environment, and Development Network for Africa, which examined the impact of climate change on energy security in East Africa, underscored that hydrological variability, and droughts in particular, disrupt energy supplies from hydropower, and that this has a damaging impact on countries' GDPs. The study emphasized that East African countries using renewables to diversify sources of electricity generation appear to survive the impacts of severe droughts better than those that rely almost exclusively on hydropower for electricity generation. The paper noted, "In comparison to Uganda and Ethiopia, Kenya appears to be more resilient to drought induced power generation shortfalls. This is largely because Kenya has a higher level of diversification of its electricity generation sources, mainly through the promotion and use of renewable energy such as geothermal, biomass based cogeneration and to a lesser extent, wind energy. As a result, Kenya's electricity supply is more secure in comparison to the neighbouring countries" (Stephen Karekezi et al., 2009).

Another concern for the hydropower sector, in the context of climate change, is elevated siltation (which affects hydropower infrastructure and turbine efficiency). High demand for firewood has led to massive deforestation in Ethiopia, which has induced severe soil erosion, particularly in the Northern Ethiopian Highlands. In Tigray, many reservoirs have filled up much sooner than expected (Haregeweyn, et al., 2006). Such large sediment load is a threat to the life expectancy of many reservoirs used in hydropower generation (Abraha, 2008). The expected increase in heavy rainfall because of climate change is, thus, a risk for hydropower in some parts of Ethiopia.

2.3.2. Increasing energy demand and the impact on climate change

Today GHG emissions from Ethiopia are mainly from rural activities, including agriculture, soil, livestock, deforestation and forest degradation. City-based GHG sources include industry, transport, buildings and services, but these are relatively small in Ethiopia compared to emissions from agriculture and forestry. At present, city-based activities are responsible for about 15 per cent of the total emissions, but this is expected to rise to 35 per cent in 2030 because of rapidly rising emissions from industry and transport. Industry and transport are the main contributors to GHG emissions in cities. Emissions from industry come predominantly from large industries such as cement and lime producers, which consume coal and petroleum coke for kilns.

The rapidly rising demand for solid fossil fuels (coal and petroleum coke) in the industrial sector will translate to an increase in emissions. The demand for fossil fuels is increasing because of the rapid rise in the establishment of new factories producing cement and the expansion of existing ones (which need cheap energy for kilns in the preparation of cement). Replacing the fuels in large manufacturing industries requires low-carbon energy options.

In the residential and services sector, the growing demand is likely to result in increased emissions from forest degradation. One of the main reasons for forest degradation is the harvesting of trees to burn in cook stoves. A growing population will increase demand for wood, thereby increasing the pressure on forests, mainly in rural areas. Increased incomes will also mean an increased demand in transport fuels, mainly for petroleum, which will further contribute to emissions. As temperatures in Ethiopia rise, these residential areas will also demand energy for space cooling. There will also be a new and increased demand for powered service delivery, for example, for ground water pumping as surface water becomes less reliable.

Ethiopia is committed to building a climate-resilient green economy. Its plan to do so comprises of actions to reduce GHG emissions while safeguarding economic growth ("green economy"), as well as adaptation initiatives to reduce vulnerability to the effects of climate change ("climate resilience"). To develop a green economy, 150 initiatives (such as those illustrated in Box 1) have been identified, and 60 have been prioritized based on their local relevance, feasibility, contribution to reaching GTP targets, and significant potential for emission reduction at a reasonable cost for the relevant sectors. If all the emission reduction initiatives that have been identified were fully implemented, Ethiopia would limit emissions to current levels in absolute terms and reduce per-capita emissions from 1.8 tonnes to 1.1 tonnes of carbon dioxide-equivalent (tCO_2e) while achieving middle-income status before 2025 (FDRE, 2011).

Ethiopia aims to achieve carbon-neutral and middle-income status before 2025. However, if Ethiopia were to pursue a conventional economic development path, represented in a business-as-usual scenario, GHG emissions would more than double to 400 million tCO_2e in 2030. Conventional economic growth could lead to other challenges as well, such as depleting the very natural resources that Ethiopia's economic development is based on, locking it into outdated technologies and forcing it to spend an ever-larger share of GDP on fossil fuel imports. In addition to diminished public health resulting from diseases related to indoor air pollution, further forest degradation and soil erosion would also occur, decreasing food security and destroying sources of drinking water (FDRE, 2011). Figure 11 shows the likely emissions growth under a business-as-usual scenario, and the sectors from which these increased emissions will come. Besides substantial increases in agriculture and emissions from deforestation already taking place, emissions from transport and industry increase to substantive contributions from a relatively low base. The case for low-carbon energy sources to meet increased energy demands from these two sectors is compelling, not only to help Ethiopia develop a low-carbon economy that is competitive in a carbon-constrained world, but also from a land degradation and energy security perspective, especially at the current rate of fuelwood consumption and land-use change.

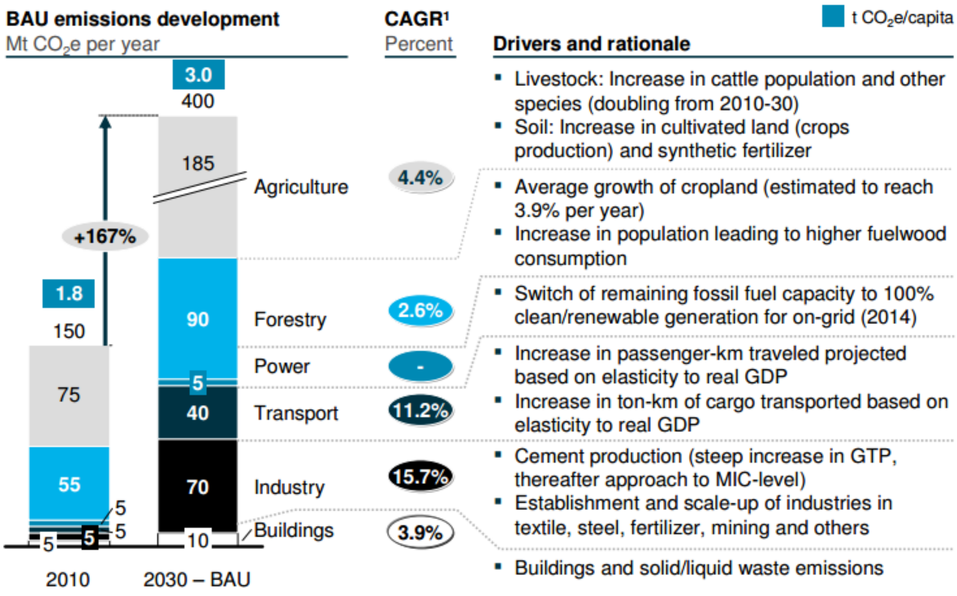


Figure 11. Greenhouse Gas Emissions from Ethiopia (Business as Usual) (FDRE, 2011)

2.4. Conclusions

Diré Dawa and Mekelle are in climate Regime A of the country and are characterized by bi-modal rainfall during June-September and March-May, with the remainder of the months being dry. Seasonal mean temperature in many areas of Ethiopia has been increasing. Decreasing precipitation and an already high drought risk pose continued threats to food security and the rain-fed agricultural economy.

Climate projections are subject to a degree of uncertainty, and while they foresee warming with a high level of confidence, the locations of where the warming will take place are not consistent universally across all studies. Long-term rainfall is forecast to increase slightly, despite short- and medium-term observation of frequent dry periods interspersed with heavy and intense rainfall levels. Projections are further complicated by the influence of El Niño/La Niña phenomena.

High and increasing population density increases climate change vulnerability as it decreases the amount of resources available per person. Sectors in which the economic effects of climate change will be most felt are agriculture, roads and hydropower infrastructure. These impacts will be felt in urban areas, including as a consequence of their resource-dependence on surrounding rural regions, which will feel many consequences directly.

Potential impacts on agriculture are most notable given that the sector contributes 50 per cent to GDP, 90 per cent of exports, and with 85 per cent of the population employed in agriculture and related activities. The most vulnerable groups are smallholder farmers, flood-prone urban poor, rural landless and children. Women are disproportionately affected by climate change impacts as they have more household responsibilities and limited coping options compared to men. Further impacts include diseases related to water quality, vector-borne diseases, heatwaves and floods.

From an energy resource perspective, the main sources of energy in Ethiopia are biomass and hydro-electricity, meaning that energy insecurity is an additional climate vulnerability because of potentially compromised supplies of both resources. Analyses of river flows show a great deal of uncertainty, particularly regarding low-season flows. A compromised energy supply would take its toll on the economy in the future, and there is already significant historical evidence for this. The vulnerability points toward a need to diversify the country's energy supply, which would also alleviate the detrimental impacts of excessive biomass harvesting, especially given the current trend of rising demand for energy. The case that a low-carbon energy mix going forward is also compelling to achieve long-term, climate-resilient energy security and energy supply to fast-growing secondary cities presents an ideal platform for fostering such a transition. A further analysis of Ethiopia's energy sector is provided in the next chapter.

3. Understanding Ethiopia's energy sector

Following the previous chapter's examination of climate change impacts and vulnerabilities (with specific attention drawn to impacts on the energy sector in Ethiopia), this chapter delves deeper into Ethiopia's energy sector. This chapter addresses energy demand and supply within Ethiopia, focussing on implications for secondary cities in terms of energy access, energy demand trends disaggregated by sector, power grid expansion plans, and the need for climate-resilient, low-carbon energy options. To understand the potential for low-carbon energy options in the future, it is necessary to understand the prevailing policy, regulatory and planning context, as well as the current costs of energy.

3.1. Background

Ethiopia has one of the lowest rates of access to electricity and to non-solid fuels; only about a quarter of the population uses electricity and 90 per cent of the population still relies on solid fuels for cooking. Despite rapid economic growth and high levels of investment in power infrastructure, improving access has been challenging. Because the population is increasing at a rate faster than the rate of growth of access to improved energy, access rates have actually been declining in Ethiopia and other countries in the region, with Ethiopia experiencing the highest annual decline in access to non-solid fuels (noting that access is dually a function of connection to the grid and affordability of electricity).

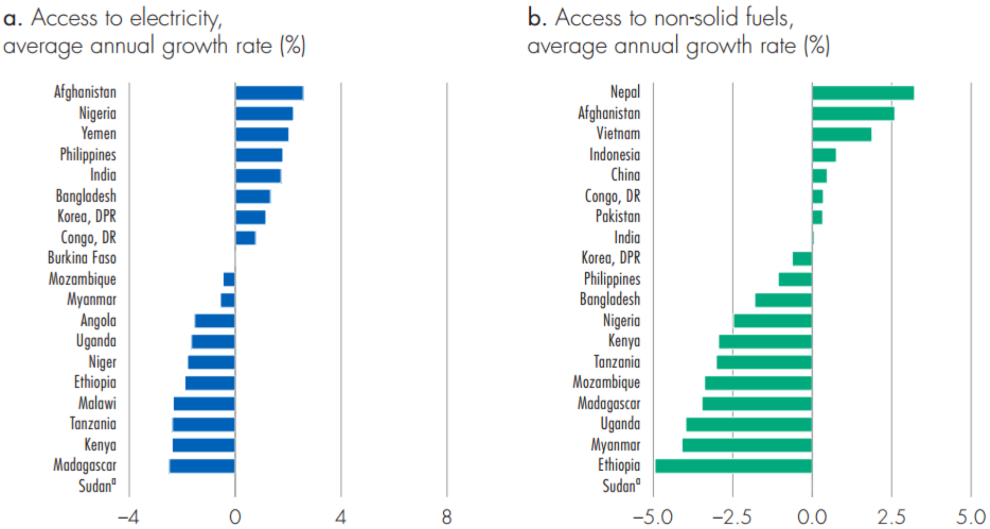


Figure 12 Country Comparison: Progress towards Sustainable Energy Targets 2010-2012 (Sustainable Energy for All, 2015)

As in most SSA countries, the gap between urban access and rural access is significant. According to the World Bank, 26.6 per cent of the population had access to electricity in 2012, whereas urban electricity access is estimated at 96.5 per cent. In contrast, only 7 per cent of rural households have access to electricity (World Bank, 2012). Of the total number of connected customers, at least 40 per cent are concentrated in the capital city of Addis Ababa. However, even those with electricity access in urban areas are prone to prolonged and recurrent power outages.

Over the last decade, Ethiopia has improved its power-generation capability and bulk power transmission network considerably and has extended the power grid to nearly all major towns across the country. Because of Ethiopia's significant efforts to increase grid connectivity, 53 per cent of towns and villages were connected to the grid as of July 2014, according to the EEP (EEPCO, 2012).

There are also significant expansion plans for Ethiopia's transmission and distribution network (see Figure 14). However, customer connection in newly electrified towns has not grown as rapidly. In contrast, electrification through off-grid technologies has seen faster growth, as exemplified by the annual distribution of solar home systems (which saw uptake by 0.35 million households in 2014) (ERCA, n.d.a).

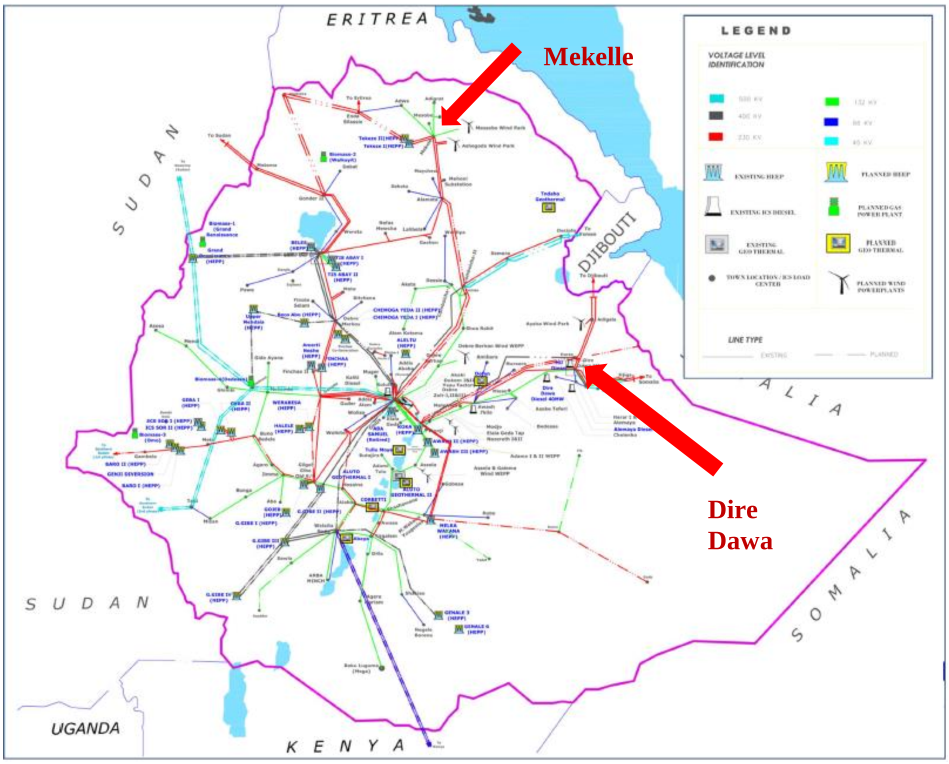


Figure 13. Existing and Planned Transmission Lines for Ethiopia (EEPCo, 2014)

3.2. Energy supply and consumption

As is typical for the SSA region, Ethiopia's total primary energy supply is dominated by biomass, which contributes approximately 93 per cent of total primary energy supply (TPES) (International Energy Agency, 2013). This proportion is higher than the reported regional average of 81 per cent (Stecher, et al., 2013).[1] The contribution of other sources of energy to TPES is limited, with oil providing 5.3 per cent and hydro 1.5 per cent. Other sources are negligible, as shown in the diagram below, which is based on 2009 International Energy Agency (IEA) data (International Energy Agency, 2015).

[1] This figure is for the Sub-Saharan African Region, excluding South Africa.

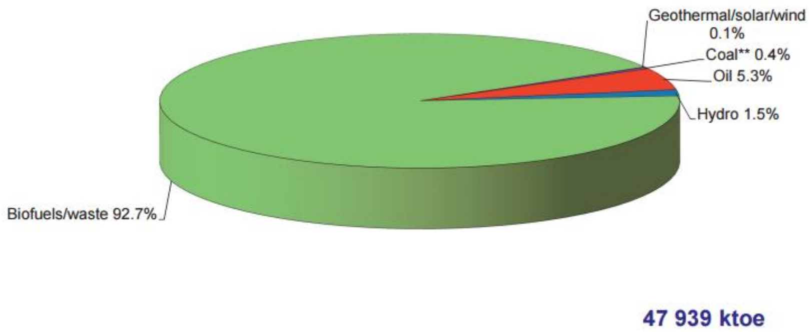


Figure 14. Share of Total Primary Energy Supply in 2013 (IEA, 2016)

Energy demand is growing rapidly in Ethiopia, as a result of economic expansion and population growth. Between 2010 and 2015, electricity consumption grew at 15 per cent per year, petroleum fuels at 9 per cent per year and biomass fuels at 6 per cent per year.[2] These high rates of growth have been sustained despite supply-side constraints (for example, millions of customers are still waiting for electricity connections, and the country has been experiencing frequent power blackouts, with inadequate supply to meet demand levels).

Total final energy consumption in Ethiopia for 2013 (and for 2014) was 35 million tons of oil equivalent (Mtoe), according to official government statistics.[3] Biomass fuels supplied 90 per cent of energy consumption, while fossil fuels contributed 8.5 per cent, and electricity 1.5 per cent of the final energy consumed. The distribution of energy consumption at the national level, by economic sector, is shown in the following graphic (Figure 15. National Energy Consumption in Ethiopia, 2014 (ktoe) (Ministry of Water, Irrigation and Electricity, 2014)). The percentages consumed by the various sectors are: households (91 per cent), industry (1.9 per cent), transport (6.3 per cent), and services (1.1 per cent). Each sector in Ethiopia has a propensity to use a particular type of energy: biomass is dominant in the household sector; petroleum in transport; and coal in industry.

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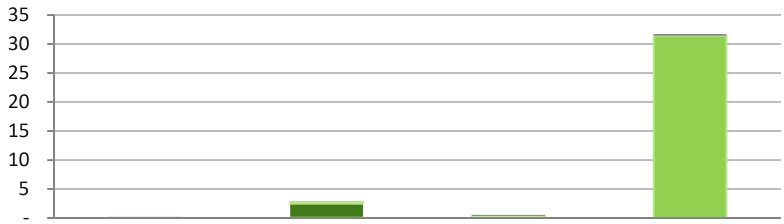
[2] Demand growth for electricity and petroleum fuels is calculated from sales and import data respectively. Biomass fuel consumption is estimated to grow at the level of domestic food production.

[3] This comprises 85 million tons of biomass (wood, charcoal, ag residues), 2.8 million tons of oil products, 5,700 GWh of electricity, and 0.32 million tons of coal. Per capita energy consumption is 1.0 t biomass, 31 kg oil products, and 63 kWh of electricity.



	Coal	Petroleum	Electricity	Biomass
Services	-	-	0.14	0.25
Households	-	0.28	0.20	31.45
Transport	-	2.21	-	0.00
Industry	0.21	0.27	0.18	-

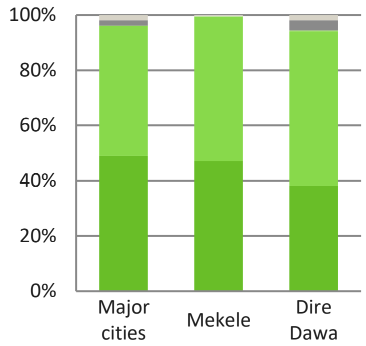
Figure 15. National Energy Consumption in Ethiopia, 2014 (ktoe) (Ministry of Water, Irrigation and Electricity, 2014)

3.3. Energy demand in secondary cities

3.3.1. Residential sector (households)

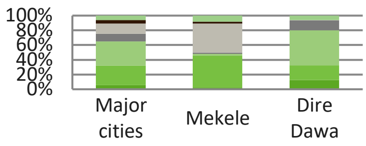
Ethiopia's major cities, which include all regional state capitals (10 of them) and 5 other relatively large urban centres (a total of 15 urban centres), are home to the main energy consumer groups. In order of importance, these consumption categories are households, transport, industry and services. In the household sector, major energy usage is for lighting, electric appliances and cooking. A 2011 survey indicates that 96 per cent of households in secondary cities used electricity for lighting, while only 14 per cent used electricity for cooking; an overwhelming 75 per cent used biomass fuels for cooking (see Figure 18).

In Mekelle, for example, virtually all households are connected to the grid (99.3 per cent), while in Diré Dawa the connection rate is slightly lower (89 per cent). In both cities, proportionally more of the population is connected to the grid through shared meters (that is, these are not customers of the power utility, but rather those who purchase their power from neighbours, usually paying significantly more for their electricity than they would have if they were directly connected to and metered by the grid).



	Major cities	Mekele	Dire Dawa
Other	1.9%	0.4%	1.9%
Kerosene	2.0%	0.0%	3.7%
Electrical battery	0.0%	0.2%	0.3%
Electricity-shared	47.1%	52.2%	56.0%
Electricity-own meter	49.0%	47.1%	38.1%

Figure 16 Energy use for lighting, 2011 (CSA, 2011)



	Major cities	Mekele	Dire Dawa
Other	6.0%	8.1%	6.1%
Agricultural waste	4.6%	2.7%	0.0%
Electricity	13.9%	39.3%	0.3%
Kerosene	10.7%	2.0%	13.8%
Charcoal	32.9%	2.5%	47.4%
Firewood-Purchased	26.4%	43.1%	19.8%
Firewood-Collected	5.5%	2.4%	12.7%

Figure 17 Energy use for cooking, 2011 (CSA, 2011)

Current biomass energy consumption per household continues to be high, with 2 kg per capita per day or an annual consumption of more than 3 tons for the average household. Electricity consumption has risen gradually in the past 20 years to 60kWh per capita per year for 2013, significantly lower than neighbouring countries.

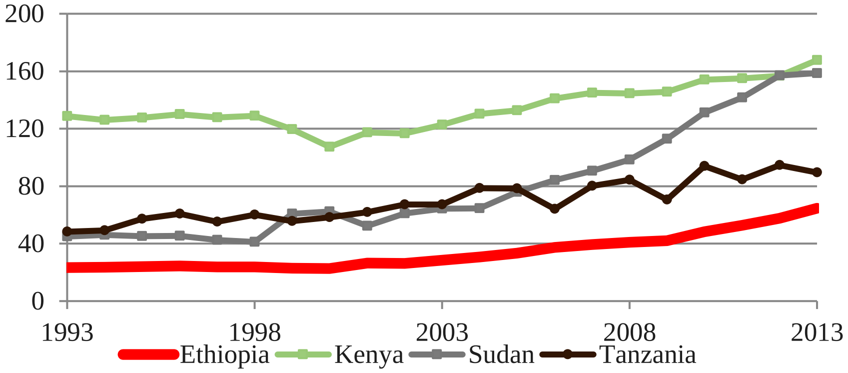


Figure 18 Electricity consumption per-capita – Ethiopia and neighbouring countries (kWh/capita/y) (World Bank, Ministry of Water, Irrigation and Electricity, 2014)

Several trends are emerging in both household electricity consumption and biomass energy consumption. First, from what the research team learned through stakeholder comments at workshops (anecdotal evidence), a slow shift may already be starting from biomass and petroleum-based cooking to electric cooking because cooking with electricity costs less compared to other fuels. Electricity consumption levels for cooking are also rising because of growing incomes in urban areas. Second, for those households still cooking with biomass fuels, consumption levels are gradually declining because of the penetration of energy-efficient stoves in the biomass cooking market.

3.3.2. Future demand

Because of rising purchasing power and a population expansion, energy needs in secondary cities are expected to increase. On average, secondary city population is expected to grow 4 per cent annually (Diré Dawa is growing at 2.07 per cent, and Mekelle at 4.13 per cent), more than a doubling of the population in 20 years. In that same period, per-capita energy consumption levels will rise significantly because of rising incomes. These two trends will result in very high rates of demand growth for electricity; biomass energy demand may stay flat because of a decrease in household biomass use and an increase in improved cook stoves. There is thus expected to be a reduction in energy intensities, or energy consumption per capita, because of the move to modern fuels and improved end-use devices and appliances.

Climate change is also affecting energy demands in secondary cities. Climate change and variability, coupled with declining productivity and uncertainty in agriculture, has led to an influx of citizens moving from rural areas into cities.

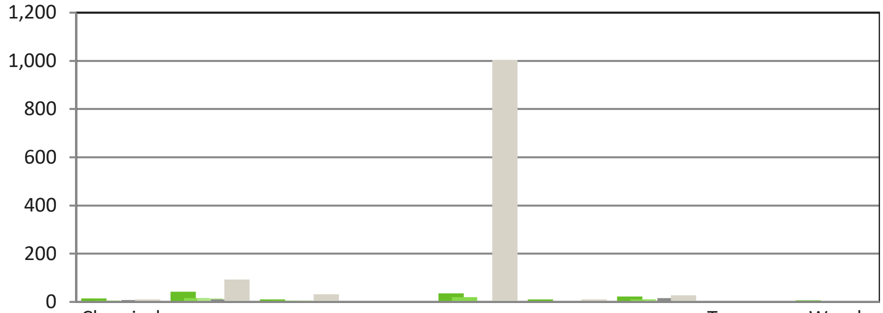
3.3.2.1. Industry

Manufacturing activity is concentrated in secondary cities. In 2013, Addis Ababa accounted for 40 per cent of the total number of medium- and large-scale manufacturing enterprises (and about the same percentage of the value of production), with the rest distributed in the other secondary cities. In small-scale manufacturing, Addis Ababa accounted for 16 per cent of the number of enterprises and for 34 per cent of the value of production, with the remaining distributed across other urban centres.

In 2013, the total value of output for the medium- and large-scale manufacturing sub-sector was ETB 103 billion ($[4]5.4 billion), and the cost of energy was ETB 3.7 billion ($194 million). Output from the small-scale manufacturing sub-sector was ETB 6.1 billion ($321 million), and the cost of energy was ETB 0.53 billion ($27.9 million). Energy costs and requirements for small-scale industries are therefore proportionately much greater than for large-scale manufacturing. The higher cost might be attributed to higher tariffs being charged to these entities. Medium- and large-scale industries are responsible for up to 90 per cent of the cost of

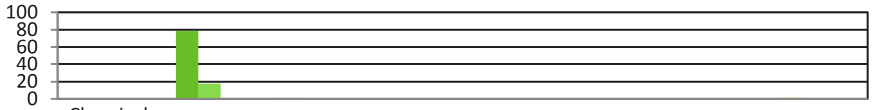
[4] All dollar amounts are in U.S. dollars, unless noted.

energy in manufacturing, with energy consumption divided among the fuel groups as follows: 64 per cent fossil fuels, 21 per cent electricity and 15 per cent biomass.



	Chemical and petrochemical	Food and tobacco	Iron and steel	Machinery	Non-metallic minerals	Paper, pulp and print	Textile and leather	Transport equipment	Wood and wood products
Electricity	15.0	43.0	10.5	0.6	36.1	10.7	23.0	0.4	6.6
Fuel oil	5.8	15.9	4.8	-	19.4	1.0	9.9	0.1	2.1
Diesel	2.2	13.9	4.8	0.0	2.1	0.2	6.7	0.2	0.8
Biomass	7.6	11.0	1.1	-	-	0.5	16.4	-	0.7
Coal and Petroleum Coke	10.0	92.7	31.9	0.5	1,004.3	9.9	28.2	2.8	3.4

Figure 19. Energy in medium- and large-scale manufacturing in Ethiopia, 2013, ktoe (CSA, 2014)



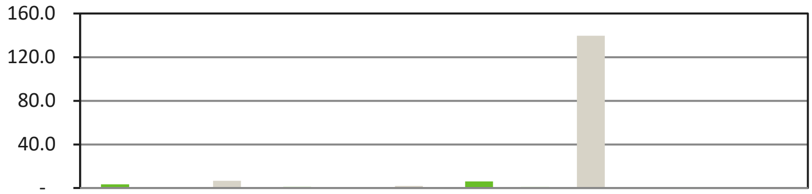
	Chemical and petrochemical	Food and tobacco	Iron and steel	Machinery	Non-metallic minerals	Paper, pulp and print	Textile and leather	Wood and wood products
Electricity	0.0	78.5	1.0	0.1	0.1	0.0	0.2	1.5
Diesel	0.1	17.7	0.1	0.0	-	-	0.1	0.1
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 20. Energy in small-scale manufacturing in Ethiopia, 2012, ktoe (CSA, 2013)

In the manufacturing sector, the principal energy consumers are cement factories (listed under the “non-metallic minerals” group), which were responsible for two-thirds of the total energy consumed. Cement factories are the main consumers of coal and petroleum coke in industry.

Secondary cities are important centres of manufacturing, responsible for 60 per cent of the national manufacturing output. Secondary cities such as Mekelle and Diré Dawa are growing manufacturing centres: Mekelle has one of the largest cement factories in Ethiopia, and Diré Dawa has four medium-scale cement factories. Mekelle and Diré Dawa are also important centres in the manufacturing of textile and food products.

In Mekelle and Diré Dawa, energy consumption in the manufacturing sector is dominated by solid fossil fuels (coal and petroleum coke used in kilns in cement factories; see figure below). Other main sources of energy include biomass, used in bakeries, and fuel oil, used as boiler fuel in most factories.



	Manufacture of articles of concrete, cement and plaster Dire Dawa	Other Dire Dawa	Manufacture of cement, lime and plaster Mekele	Other Mekele
Electricity	3.5	0.9	6.0	0.9
Biomass	-	0.3	-	0.9
Fuel oil	0.8	0.3	1.0	0.1
Diesel	-	0.0	-	0.0
Coal and petroleum coke	6.6	1.9	139.6	0.9

Figure 21. Energy in medium- and large-scale manufacturing in case study cities, 2013, ktoe (CSA, 2014)

In a drive to increase the contribution of manufacturing in the economy, the government is building several industrial parks in Addis Ababa and selected cities (Mekelle, Diré Dawa, Bahir Dar, Gondary, Awasa, Jimma and Kombolcha). Each of these industrial parks is estimated to require 300 MW of power in the first years of operation and will consume 1,500 GWh of electricity by 2022 (EEPCO, 2014. Ethiopian Power System Expansion Master Plan Study, Volume II). Energy-intensive industries such as cement and iron and steel are expected to take two-thirds of the electricity requirements of the parks. These industries will have high requirements for fossil fuels for thermal applications.

Table 2. Proposed industry parks in case study cities (EEPCo, 2014)

Industry zone	Area (ha)	Electricity demand (MW)
Diré Dawa (Melka Jebdu)	1 051	315
Mekelle	1 000	300

3.3.2.2. Services

The services sector is composed of commercial services and social services. Commercial services include enterprises engaged in hospitality and trade. Social services include public services such as health, education, water supply and detention facilities.

Figure 22. Energy requirements per enterprise for hospitality and social services, 2015 (ERG, 2015)

Within the commercial services sector, the hospitality sub-sector (restaurants, bakeries, local bars) is the main energy consumer. Food and beverage enterprises have high energy requirements for cooking, baking and hot water preparation; the concentration of these enterprises in secondary cities is also high (in terms of the number of enterprises per 1,000 people).

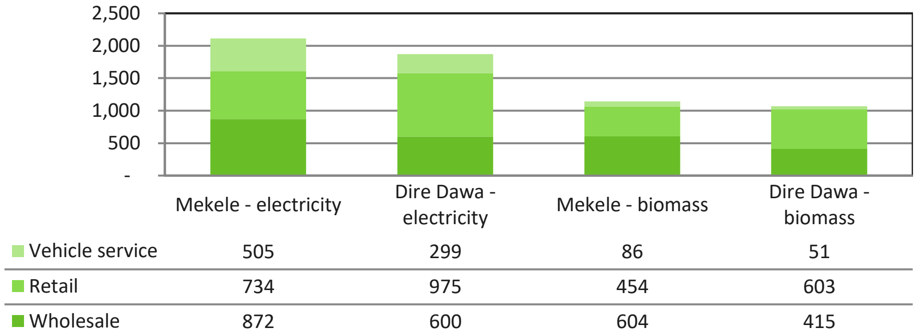


Figure 23 Energy consumed in the trade sub-sector in the case study cities, toe, 2014 (CSA, 2015)

Growing income and population will drive future energy demand in the services sector. The service sector is projected to grow at 10 per cent annually over the next 5 years (FDRE, National Plan Commission, 2015. The Second Growth and Transformation Plan, 2016-2020). This rapid growth in the services sector is likely to result in proportionally rapid growth in energy demand for the sector.

3.4. Considerations for climate change resilience and low-carbon development

3.4.1. Low-carbon options

Earlier sections of this monograph discuss the impact of climate change on Ethiopia's existing energy supply (biomass and hydropower) and highlight why the lack of access to adequate and reliable energy services constrains rapid growth of productive economic activity. Both are challenges for Ethiopia, and Ethiopian cities in particular, to be resilient to environmental and economic shocks.

A key factor that would contribute to strengthened resilience is greater diversity in the country's power mix. Clean energy development (and in particular, renewable energy) could play a significant role in this regard. In fact, in the next 25 years, hydropower resources may be fully utilized, necessitating exploration and scale-up of other renewables, including wind, geothermal, solar and biomass.[5]

The search for low-carbon options will rely on the availability of local resources, in and around secondary cities, to meet local needs. There are already projects underway to help fulfil these needs. Some of these projects are:

- Waste-to-energy[6] projects in secondary cities
- Improved cook stoves for households
- Energy efficiency for industries
- Small- and medium-scale renewable power plants, ranging from biomass to sugarcane bagasse to small hydropower
- Alternative fuels for industries (such as improved biomass for cement industries)
- Solar thermal for heating services (particularly water heating)
- Ethanol for cooking to replace non-sustainable biomass and petroleum fuels.

There are also energy options that are not renewable or very low carbon, but still less carbon-intensive than traditional biomass or coal and petroleum:

- LPG for cooking in the residential and service sectors
- Natural gas for cooking and other thermal uses in cities in the East, where some natural gas reserves have been identified (Diré Dawa may be a beneficiary).

3.4.2. Current regulatory and planning context

The **National Energy Policy** of Ethiopia was revised in 2012 to align with current global, national and sector-wide realities. Changes in the national economy and the resultant changes in the country's energy needs drove the revision. Additionally, the policy was informed by new international priorities such as climate change mitigation and adaptation, new opportunities

[5] Ethiopia's technically exploitable hydropower potential is 45-48 GW while the economically exploitable potential is 22 GW (Hydrochina, 2015: Hydropower Potential General Survey in Ethiopia). On the other hand, the current power system development master plan estimates demand to reach 26 GW in the reference case and 32 GW in the high demand case by 2037 (Parsons Brinckerhoff, 2014. Ethiopian Power System Expansion Master Plan Study – Draft Final Report, Volume 2, Part 2: Load Forecast Report and Distributed Load Forecast Report).

[6] Waste-to-energy as defined here should be an umbrella term for waste-water to energy, solid-waste incineration, landfill gas extraction, or biodigester technologies.

such as regional power interconnections, and new national development agendas such as technology localization.

The policy's primary goal is to ensure the availability, accessibility, affordability, safety and reliability of energy services, to support accelerated and sustainable social and economic development and transformation of the country. The policy seeks to meet the following six objectives:

1. Improve the security and reliability of energy supply and for Ethiopia to be a regional hub for renewable energy
2. Increase access to affordable modern energy
3. Promote efficient, cleaner, and appropriate energy technologies and conservation measures
4. Strengthen energy sector governance and build strong energy institutions
5. Ensure environmental and social safety and sustainability of energy supply and utilization.
6. Strengthen energy sector financing.

The National Energy Policy recognizes the limited diversity of the current power generation mix in Ethiopia (more than 95 per cent of the energy delivered comes from large hydropower plants). Such limited diversity reduces security and reliability of electricity supply, which in turn creates economy-wide risk. The policy, in response, promotes diversity in the power generation mix from wind, geothermal, solar and biomass; it also promotes regional integration to mitigate these risks (MoWIE, 2012).

National Development Plans are developed every 5 years in Ethiopia. Increasing energy production was a priority under Ethiopia's last 5-year **Growth and Transformation Plan (GTP I)**, which aimed to achieve GDP growth of 11 per cent–15 per cent per year from 2010 to 2015. This emphasis on GDP growth, coupled with energy sector expansion, is also reflected in the Second Growth and Transformation Plan (GTP II) (Tessama, et al., 2013). The GTP II contains an energy sector plan for 2015-2020. The tables below show growth targets for the power subsector and for the alternative energy subsector.

Table 3. Power Sector Plan Targets

Generation (MW)	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
Hydropower	1,954	4,828	4,828	10,078	10,078	13,957
Wind	171	622	922	1,222	1,222	1,222
Solar		300	300	300	300	300
Geothermal	7	7	7	277	377	577
Gas turbine	89	89	89	159	509	509

Waste to energy		50	50	50	50	50
Bagasse		354	434	434	474	474
Other biomass		138	258	258	258	258
Total	**2,221**	**6,388**	**6,888**	**12,778**	**13,268**	**17,347**
Transmission (km)	**014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**
500 kV		1,240	1,240	1,240	1,240	1,240
400 kV	1,107	649	1,134	1,300	1,700	2,137
66-132 kV	11,718	13,940	15,923	16,757	17,357	18,351
Service	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**
Access (per cent)	60%	63%	67%	74%	82%	90%
Customers	2,455,000	2,955,000	3,955,000	4,955,000	5,955,000	6,955,000

Table 4. Alternative Energy Plan Targets (National Planning Commission, 2015)

Type, systems	**2019/20, number of units**
Biomass energy	
Improved fuel saving cook stoves	11.45 million
Biofuel household stoves, biofuel processing technologies	20,000
Biogas	31,400
Solar energy	
Solar home systems	400,000
Institutional solar systems	3,600
Solar lanterns	3,600,000
Solar water heaters	5,000
Solar cookers	3,600
Solar mini-grids	250
Solar water pumps	50
Solar technician training	1,500
Wind water pumps	**300**
Micro hydropower systems	**105**

3.4.3. Current cost of energy

The main electricity producer and supplier in Ethiopia is the state. Two state companies, EEP and Ethiopian Electricity Utility (EEU), are responsible for power production and transmission and for power distribution and sale, respectively. Annual electricity sales from the state utilities currently stand at about 6,000 GWh.

Electricity tariffs are very low in Ethiopia, ranging from USD$1.7/kWh (residential customers) to USD$3.2/kWh (commercial customers). The combined domestic tariff is USD$3.0/kWh. The export tariff is USD$7.0/kWh. Electricity tariffs in Ethiopia have not been revised for more than 8 years despite rapid depreciation of the Ethiopian currency against the U.S. dollar (the currency exchange rate has depreciated 58 per cent since 2005 and 37 per cent since 2010).

Table 5. Electricity tariff, Ethiopia (EEP 2014)

Tariff class	Tariff range – ETB/kWh	Median tariff – ETB/kWh	Median tariff – US$¢/kWh	Tariff class contribution to total sales
Residential	0.27 – 0.69	0.35	1.66	34%
Commercial	0.61 – 0.69	0.67	3.19	23%
Industrial – Low Voltage	0.58	0.58	2.76	16%
Industrial – 15 kV	0.41	0.41	1.95	6%
Industrial – 132 kV	0.38	0.38	1.80	7%
Export	1.47	1.47	7.00	14%
All			**2.96**	**100%**

Ethiopia does not produce fossil fuels; it imports its entire requirement for these fuels (petroleum fuels mainly for transport and coal for industrial thermal applications). Ethiopia has recently started exporting power to Sudan and Djibouti, and a transmission link is under construction to Kenya. In 2014, electricity exports were 730 GWh (or 12 per cent of the total electricity distributed to consumers).

3.4.4. Policies to promote low-carbon development

Ethiopia is already undergoing a policy shift to encourage increased penetration of low-carbon technologies. At present, Ethiopia has one of the lowest electricity tariffs in the world because of large government subsidies. The true economic costs of electricity are estimated to be two to three times current tariffs.[7] Unfortunately, the heavily subsidized rate for electricity renders non-hydro renewable sources of power financially unattractive.

In the future, the cost of electricity is expected to increase, as low-cost hydropower sites are exploited and development starts moving towards more expensive sites. A study for the EAPP indicates that power generation costs alone will rise from $3.0/kWh today to $7.0/kWh in the next 15 years.

There is speculation within Ethiopia's energy sector that such an anticipated rise in costs would prompt the introduction of feed-in tariffs to encourage medium-scale power generation projects from IPPs (private and public), including waste to energy, solar and wind power projects.

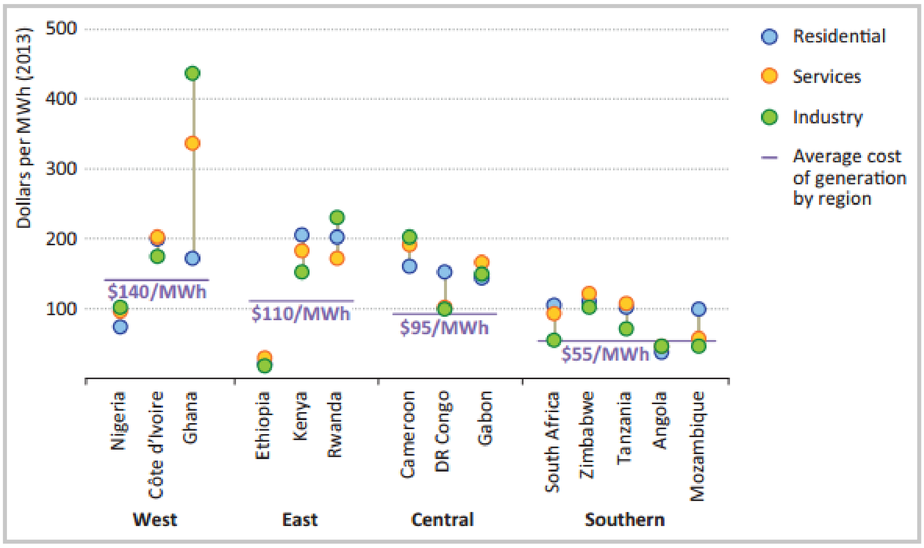


Figure 24. Electricity price in selected countries in Africa, 2013 (IEA, 2014)

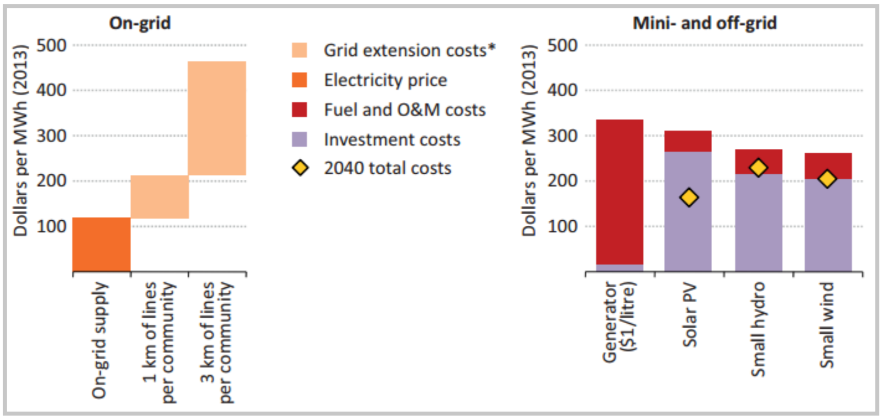


Figure 25. Indicative levelized costs of electricity for on-grid, mini-grid and off-grid technologies in sub-Saharan Africa, 2012 (IEA, 2014)

[7] The current tariff is just under USc 3/kWh; power generation costs from candidate plants ranges from USc 2.6/kWh to USc 17/kWh with mean generation costs being between USc 7/kWh (Parsons Brickerhoff, 2014. Ethiopian Power System Expansion Master Plan Study – Draft Final Report, Volume 3. Generation Planning).

From Figure 24, the low cost of electricity relative to its neighbouring countries is indicative of the possibility of an increase in cost in the event of regional integration, which would compound current efforts to improve electricity access to Ethiopian citizens. The competitive cost of solar PV (PV), mini-hydro and micro-wind for mini-grid supply is shown in Figure 25. Also, evident from the two graphs is the high cost of grid extension, showing a threshold of just over 1 km of transmission lines at which off-grid, or min-grid solutions become more economically viable. These comparisons do not consider the potential for inclusive growth and job creation, which is likely to be greater under the mini or off-grid supply option compared to the on-grid supply option.

3.5. Conclusions

This third chapter laid out the energy supply and demand context in Ethiopia and outlined some of the ramifications for secondary cities regarding energy demand growth. Despite rapid economic growth and grid and generation expansion, adequate access to electricity and non-solid fuels has been declining for the growing population, and supply is unreliable. A growth spurt has begun in off-grid electrification through solar home systems.

Biomass dominates Ethiopia's energy mix at 93 per cent of total primary energy supply, with negligible contributions of other energy sources, so there is potential to diversify supply and thereby create a more secure long-term energy mix.

In secondary cities such as Diré Dawa and Mekelle, electrification rates are edging towards 100 per cent, with most of the usage of this electricity attributed to lighting. Informal onward selling of electricity (at a premium) inflates end-use electricity prices to many users. Cooking fuel needs continue to be met by biomass, though consumption is mitigated somewhat in a few locations by the roll-out of energy efficient stoves. Energy needs in secondary cities are expected to increase because of increasing population and rising incomes and because of their importance as manufacturing centres and their growing services sectors.

Low-carbon options in and around secondary cities include waste-to-energy, improved cookstoves, energy efficiency for industries, small- to medium-scale renewable plants, alternative fuels (such as improved biomass for cement industries), solar water heating and liquefied petroleum gas/natural gas for cooking.

4. Inclusive growth in future Ethiopian cities – An energy services lens

This chapter examines the potential for inclusive growth in Ethiopian cities through the lens of energy services. The pressures resulting from rapidly growing, resource-constrained cities will most likely be exacerbated by climate change. The potential for various low-carbon resources to improve energy security are considered in turn, in terms of energy resource potential, economic viability, and the applications of these resources in different sectors (industries, household and services). The co-benefits (such as improved health, reduced environmental degradation, gender justice, and broad-based socio-economic development) of low-carbon energy sources are also unpacked. A number of regional country examples are given by way of comparison and allude to the types of initiatives that may be useful in the Ethiopian context.

4.1. Growing cities

As discussed in Chapter 1, cities in Africa are growing both in size and population. High rates of urbanization will be one of the most significant dynamics that affect the future of most African nations. In the coming decades, the highest urban populations in the world will be in SSA, reaching 52 per cent urbanization by 2050 (Centre for Liveable Cities, 2014). As the figure below demonstrates, SSA has the steepest projected urbanization rates. As such, African cities will face bigger challenges from high population size and high rate of urbanization than almost anywhere else in the world. These challenges, coupled with climate change impacts that could affect existing energy sources (such as hydro and biomass) and create new and increasing demands for energy (such as cooling), need to be managed through well-planned, sustainable development pathways that are tailored to each African country's own needs.

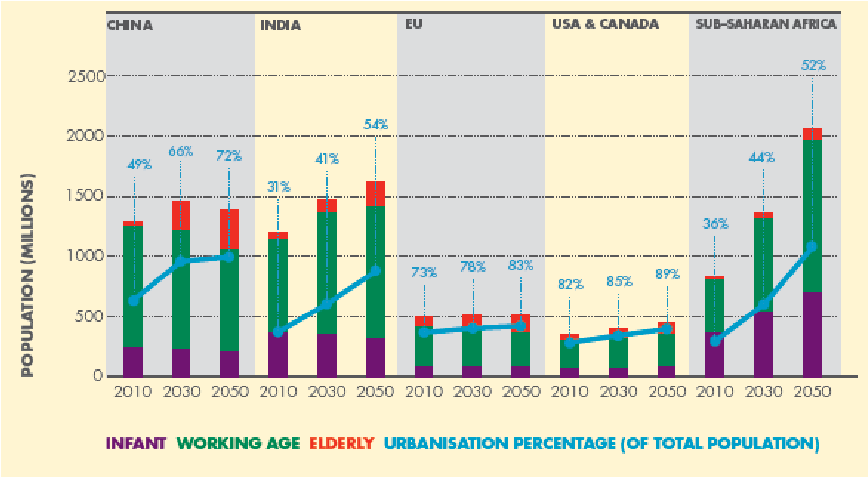


Figure 26: Regional population demographics and urbanization (Centre for Liveable Cities, 2014)

In Ethiopia, urbanization is currently about 20 per cent, but has grown at a considerably higher rate in the past decade. Urbanization may bring both opportunities and risks. Growing demand for resources will create stress on existing infrastructure, and poorly managed urbanization can lead to declining quality of life, greater environmental degradation, and accelerating GHG emissions. In contrast, well-managed urbanization can bring benefits through efficiency and greater concentration of productive economic activity, and by becoming supportive environments for innovation and knowledge generation.

In most cities, the rapid urbanization described above is going to overlay existing resource constraints and institutional capacity challenges. Furthermore, a rise in income levels means a greater probability of more consumptive lifestyles, elevating the demand for more energy services. This pressure will likely be exacerbated by climate change, with worsening resource constraints on water, food, and energy.

4.2. Need for low-carbon energy supply options in cities

As described in section 2.3.1, hydropower and biomass are the energy sources most vulnerable to climate change. As it happens, these resources are among the most widespread means of modern (hydropower) and traditional (biomass) energy supply in most African countries today. Climate change projections suggest that existing energy sources in Ethiopia are vulnerable, such as hydropower. Besides growing Ethiopian cities, the Ethiopian government must recognize challenges to future energy security and the negative socio-economic impacts of inadequate or unreliable energy supply. To counteract these growing challenges, Ethiopian cities should develop their policies and urban plans so that novel, but locally appropriate, energy generation, distribution and supply options are fully explored. Several factors govern feasibility of low-carbon energy supply options. Some examples include the availability and potential of renewable energy sources, the affordability of conversion technologies, and the ability of such resources and technologies to provide the required quality of energy demanded.

It should be noted that cities in low-income countries such as Ethiopia, with very low contribution to the global GHG emissions, are not obliged to take mitigation measures or adopt low-carbon development pathways. However, to have more assured energy supply, low-carbon energy options such as non-hydro renewables could allow cities to benefit from a more climate-resilient energy supply.

4.2.1. Energy resources

Ethiopia is rich in renewable energy resources, including hydropower, geothermal, wind and solar energy. Hydropower and geothermal are options for baseload power, while solar and wind can provide intermittent power. These sources are described below in further detail.

4.2.1.1. Hydropower

Ethiopia has significant potential for hydro-power expansion at low cost.

Ethiopia's hydropower potential is estimated at approximately 45,000 MW, the second largest in Africa after the Democratic Republic of Congo (Gamma Systems, 2012). Between 15,000 MW and 30,000 MW are estimated to be economically feasible to exploit (Derbew, 2013); 50 per cent of this resource is from just one river basin (the Abay, or Blue Nile, basin). At present only 5 per cent of the total resource is exploited (IWMI, 2007).

The cost of hydropower is low in Ethiopia, compared to that of regional and international peers. At $1,200 per installed kW, the costs are approximately half that of most other plants being built in eastern Africa (World Bank, 2007).

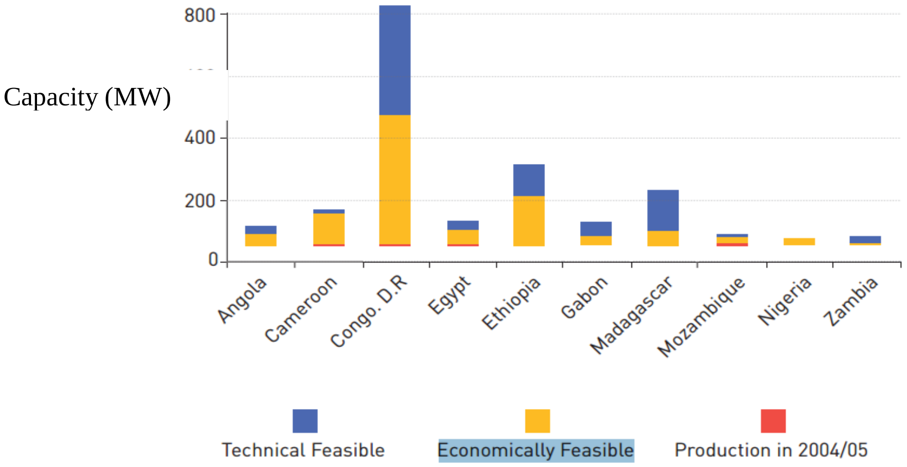


Figure 27 African Hydropower Potential (FAO, 2008)

The levelized cost of power supply for hydropower plants is estimated at $0.050-$0.067 per kWh, one of the lowest in the world. This cost is in striking contrast to Ethiopia’s regional neighbours, which are facing average generation costs ranging between $0.15 and $0.24 per kWh from thermal power options (Ministry of Water and Energy, 2012).

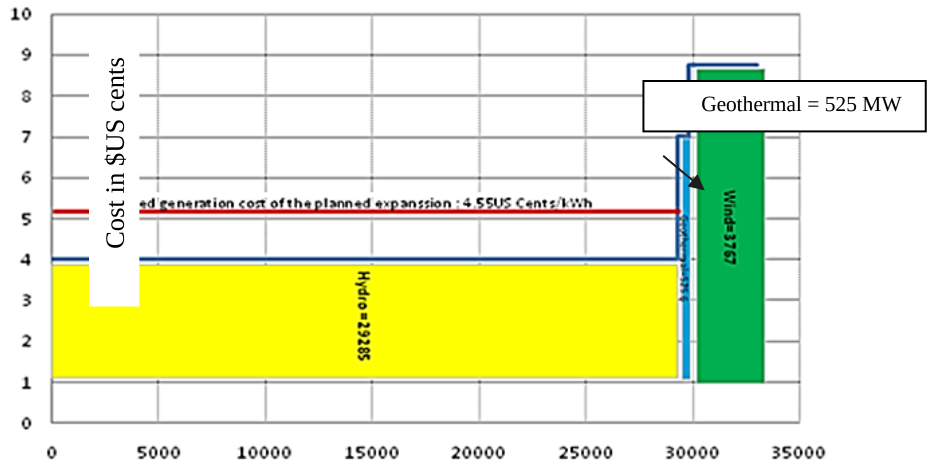


Figure 28: Unit Generation Cost by Source Type (Ministry of Water and Energy, 2012)

Ethiopia has a large hydropower resource, estimated at 159 TWh/year (30-45 GW generation capability). Hydropower accounts for more than 98 per cent of power generation in Ethiopia (EEPCO, 2012).

4.2.1.2. Wind

Wind power is already being experimented with, at significant scale.

Wind power is becoming an important source of power generation in the Ethiopian power system, second to hydropower. Ethiopia has good wind resources by international standards, with velocities ranging from 7 to 9 m/s at 50 m above ground level. Its wind energy potential is estimated to be 10,000 MW (Ministry of Water and Energy, 2012), with possible sites located in accordance with Figure 30 below. Currently, a total of about 324 MW of wind power installed capacity is in operation in Ethiopia, with plans to increase up to 1,500 MW in the next 5 years (GTP2, 2015). The seasonality of wind production suggests the potential for complementarity with hydropower resources as shown in Figure 29 below.

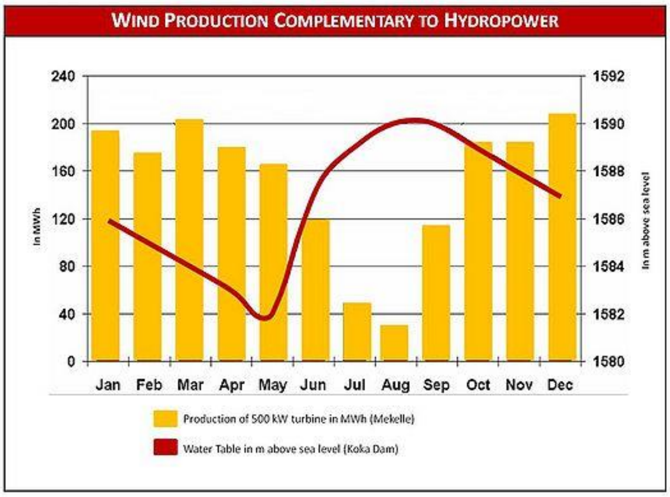


Figure 29 Wind Production Complementary to Hydropower - Example Comparing Wind Production in Mekelle and Hydropower Production at Kota Dam (Singh, 2013)

Ethiopia's 120 MW Ashegoda Wind Farm, the biggest in Africa, began production in 2013. It now generates 400 kWh a year, and supplies power to approximately 3 million Ethiopians (it is in the Tigray region, close to Mekelle). A number of new sites are also under evaluation, with a potential capacity of 542 MW (Derbew, 2013).

The estimated wind resource potential in Ethiopia suggests wind regimes at 6.5 m/s and greater could support generation capacity of 1,350 GW (MoWIE, 2011). With hydropower being the main power generation base for Ethiopia, wind and other intermittent energy sources could be added to the system at significant scale. While there is a risk that climate change could negatively affect wind generation infrastructure or modify wind patterns, with proper planning and design wind power can help supplement hydropower and mitigate power shortages.

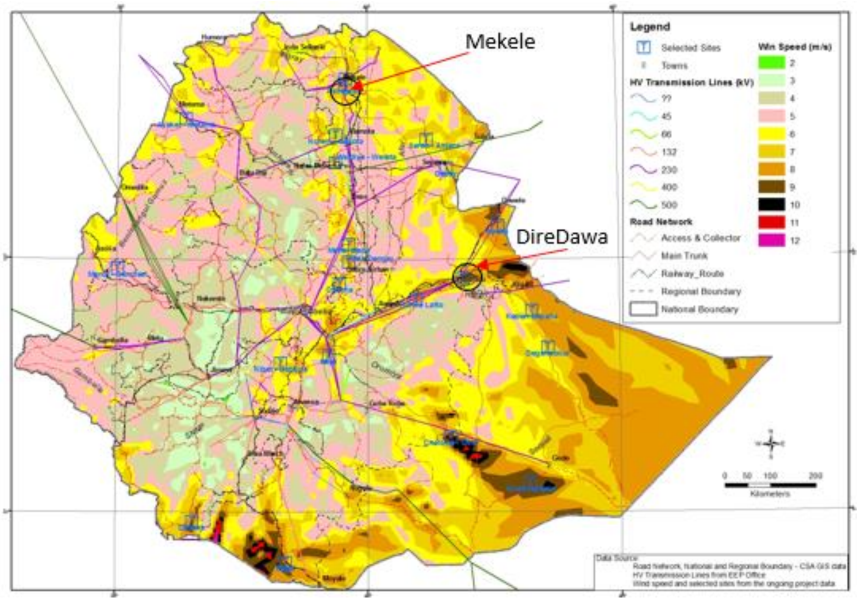


Figure 30 Meso scale wind map of Ethiopia (MoWIE, 2015)

4.2.1.3. Geothermal

Geothermal can also provide significant baseload power; although nascent, it is expanding quickly.

Geothermal energy in Africa is concentrated in the Great Rift Valley area, crossing the continent from the east from Djibouti through Ethiopia and Kenya to Mozambique. In Ethiopia, geothermal resources are scattered over a wide area (150,000 km^2) stretching from the northeast to the southwest. Exploration of geothermal energy in Ethiopia began in the early 1970s and continued through the 1980s and 1990s, with surface investigations, temperature gradient wells and test drillings at specific sites (MoWIE, 2015).

Ethiopia has a geothermal potential of 4,200 MW–15,000 MW (MoWIE, 2015). Current production is only 7 MW.

The country's first pilot plant was established at Aluto Langano in 1998, and production from this plant accounts for Ethiopia's total current installed capacity of 7 MW. However, geothermal power generation capacity is expected to increase to 70 MW with grants of $12 million from Japan, $13 million from the World Bank, and $10 million from the Ethiopian government (African Review of Business and Technology, 2014).

A range of new geothermal plants is now being developed as part of the Master Plan on Development of Geothermal Energy in Ethiopia, including:

- Aluto Langano geothermal expansion – 70 MW (due to come online in 2018)
- Tendaho Alalobeda 1st phase – 25 MW (2017)
- Tendaho Dubti shallow reservoir – 12 MW (2018)
- Corbetti Geothermal Power 1st phase – 500 MW (2018) (MoWIE, 2015).

According to the Ministry of Water Irrigation and Energy, the following long-term efforts are being planned:

- Geothermal long-term power development: 2,500 MW by 2030 and 5,000 MW by 2037
- Preparation of a new geothermal legal and regulatory framework and institutional design, due at the end of 2015 (MoWIE, 2015).

Geothermal energy potential is therefore substantial, and medium-term expansion plans are ambitious, but in early stages of development they offer the possibility of diversifying baseload away from hydropower, and offer a potentially climate-resilient energy resource.

4.2.1.4. Solar

Emergent attempts are being made to harness world-class solar potential.

Ethiopia is endowed with very good solar resource potential. The average solar energy resource in Ethiopia is about 5.5 kWh/m^2/day (MoWIE, 2011). Another source indicates that Ethiopia receives daily solar irradiation of 5,000-7,000 Wh/m^2, one of the highest rates in the world, suggesting significant potential to expand the use of solar energy (REEEP, 2014). Despite high technical potential, solar power production remains limited, and the country has reported installed capacity of just 5 MW vs. an estimated potential of 52 MW for PV alone in 2014 (GIZ, 2009).

Solar energy is currently used for off-grid rural electrification in Ethiopia through solar home systems and non-residential systems (such as for health clinics, schools and water pumping). There are plans for large-scale solar (PV) system installation for grid applications in the current power system expansion plan (300 MW). Ethiopian Electric Power is aiming to develop a 300 MW new solar project in Ethiopia and has entered into a memorandum of understanding with U.S.-based Green Technology Africa (GTA) to develop solar energy plants in the country (Mutei, 2015).

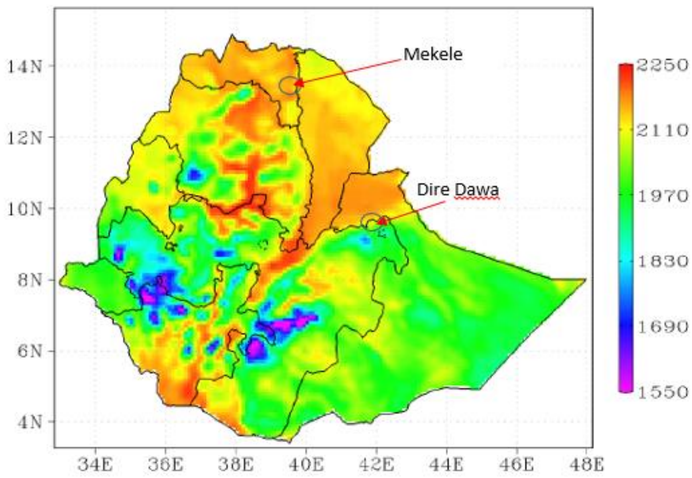


Figure 31 Distribution of average annual total solar radiation (kWh/m2/year) (MoWIE, 2012)

Table 6 shows the potential of the various energy resources, along with the exploitable reserve and the proportion currently exploited.

Table 6 Summary of Energy Resource Potential (MoWIE, 2012)

Resource	Unit	Exploitable Reserve	Exploited Percent
Hydropower	MW	45,000	< 10%
Solar/day	$kWh/^2$	Average 5.5	< 1%
Wind: Power (Speed)	GW (m/s)	1,350 (>6.5)	< 1%
Geothermal	MW	7,000	< 1%
Wood	Million tons	1,120	50%
Agricultural waste	Million tons	15 - 20	30%
Natural gas	Billion m^3	113	0%
Coal	Million tons	300	0%
Oil shale	Million tons	253	0%

4.2.2. Energy demand in cities and appropriateness of low-carbon resources

Densely populated cities have the dual prerogative of fulfilling distinct entity or sector needs, such as those for households, businesses and industries, as well as large-scale citywide needs. This allows cities to explore different power-generation and supply options for different segments of customers and energy service users, and to take advantage of synergies. City-level management of basic service provision, as opposed to regional- or national-level management, is already in place in terms of water and sanitation services. A similar model whereby the city could play a greater management role in power generation and supply is one worth investigating.

In recent years, technological innovation and advancement globally has enabled distributed generation of energy from renewable resources and improved efficient utilization of these resources while providing opportunities for cities' growth. There is scope for Ethiopia to adopt the same experience. Even though most secondary cities in Ethiopia are not new, they have only recently started modernization of service provision. This transition towards more agency at the local level can provide cities with an opportunity to influence their energy infrastructure. As city administrations start playing a more active role in self-governance, they can start considering low-carbon energy options to serve local needs, and try to adopt efficient technologies from the outset rather than having to deal with expensive retrofits at a later date.

Each city will follow its own development trajectory, adopting locally appropriate infrastructure. Development of energy infrastructure and improvement of energy services will be influenced by geography and climate, social and cultural preferences, availability of financial resources, and political and institutional capacity of individual cities to plan and implement. However, most secondary cities in Ethiopia, and in East Africa, have some common characteristics and energy-use profiles.

Urban energy supply and consumption patterns in secondary cities in Ethiopia can be broadly characterized by some key factors: type of energy source, the delivery method, and end-use sector (household, commercial, industry and urban agriculture).

Household energy demand in cities in Ethiopia is predominantly for cooking, lighting, refrigeration, heating water and powering entertainment and communication devices. Solid biomass fuels (chiefly charcoal) meet most of the cooking energy demand in secondary cities in Ethiopia. In recent years, households have shown a tendency to shift from kerosene to electricity because of the lower costs of electricity. Moreover, the new form of compact urban settlement with condominium housing compels use of cleaner fuels, like electricity, for cooking.[8] However, frequent power outages, which continue to keep the reliability of grid electricity in question, force households to adopt "fuel-stacking," with fossil fuels as a strategy for alternative fuels in times of outages.

Electricity consumption per capita is very low in Ethiopia, but is now increasing. Electricity consumption per capita has nearly tripled from about 23 kWh in 2000 to 65 kWh in 2013 (EEPCO, 2012). This level is still low compared to countries in the region; per capita consumption rates are 90 kWh for Tanzania, 160 kWh for Kenya and 170 kWh for Sudan. Such low per-capita consumption of electricity can be attributed to the low electrification rate and to limited electrification, but in the case of Ethiopia probably has more to do with affordability, appliance ownership and cultural factors. Urban households are now shifting from biomass and kerosene to electricity for cooking, and this is expected to increase electricity consumption levels. There is therefore a need to promote energy efficiency for electric cooking as well as alternative renewable energy cooking fuels (such as ethanol) in urban areas.

If one compares individual entities, energy demand in commercial establishments and the service sector is generally higher than household consumption. Most businesses in cities are

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[8] The government has been building condominium houses as part of its **Integrated Housing Development Program** since 2004. Typically, these houses are four-storey buildings with basic features inside. They are built both in the centre of cities or in peripheral areas at low cost. Up to January 2014, over 800 million dollars was earmarked for the housing projects in cities across Ethiopia. According to the Ethiopian Housing Development Agency, some 22,000 condos were handed over to beneficiaries in 2014 alone. Regional governments transferred about 76,000 houses to individuals in 2014. The construction of 65,000 houses commenced in 2013 and construction of the same number of houses will begin in 2014. (http://www.urbanafrica.net/news/ambitious-housing-project-revamping-ethiopian-cities/; Accessed date 11 April 2016)

related to catering services such as hotels, restaurants and cafeterias, where much of the energy demand is for cooking. Biomass (firewood and charcoal), electricity and gas are the most widely used cooking fuels. Non-cooking energy requirements in the service sector in cities relate to water heating, lighting, refrigeration and entertainment devices, which are fully powered by electricity.

Understanding energy usage in cities allows one to gain insights into where and how low-carbon energy from non-hydro renewables can play a role. For instance, in both the household and service sectors (including hospitality), solar water heaters represent low-hanging fruit that could be deployed quite easily.

Even though the industrial base in Ethiopia is low, cities' development agendas include the construction of industrial parks. This represents a need for greater energy supply in and around cities. Most secondary cities in Ethiopia have medium- to large-scale industries, such as textile and cement factories. For instance, there are four cement factories in Diré Dawa and one in Mekelle. High thermal energy requirements in these industries are currently met with coal and furnace oil. This represents an opportunity for cleaner fuel substitution if replaced with appropriately combusted biomass briquettes from agricultural wastes. The Mosobo Cement Factory in Mekelle has already begun a pilot trial. Other industries that require thermal energy for processing can also benefit from similar lower-carbon energy sources (while biomass is not low carbon, using it within a closed industrial process is less carbon-intensive than using coal).

Urban agriculture is more a phenomenon of secondary cities than it is of megacities like Addis. Because secondary cities are growing not only in terms of population, but also physically encroaching upon the surrounding rural areas, cities subsume farmlands. While in some cases land-use changes, in many cases this leads to farming becoming a major means of livelihood for groups of urban dwellers. In this context, alternative energy sources and generation technologies could serve these semi-urban farming communities. Solar PV, solar pumps and biogas technologies are well suited to meet the electrical and thermal energy needs by farmers at the periphery of cities.

4.3. Feasible low-carbon energy technology options

Non-renewable energy resources in Ethiopia, such as natural gas, coal and oil shale, have yet to be exploited because of quality and cost-ineffectiveness. However, planning is already underway for the development of natural gas for use in areas where the resource is located, that is, in the eastern region of Ethiopia. It is primarily being considered for cooking and other thermal uses in cities in the eastern part of the country, including in cities like Diré Dawa, Harar and Jijiga. While natural gas is still a fossil fuel, it is cleaner than coal and petroleum. However, to the extent it replaces electricity from hydropower, it should not be considered a form of low-carbon energy development.

Fortunately, Ethiopia, is endowed with considerable renewable, low-carbon energy resources, such as solar, wind, hydro, and geothermal. Thus, for Ethiopia, low-carbon energy sources are a feasible alternative. For these sources to be harnessed at the city level, critical factors that city would need to consider are the availability of the resource and the cost of energy generation. Most secondary cities in Ethiopia are in areas with potential for solar and wind, and several are in areas that are suitable for micro/small hydro and geothermal. Almost all secondary cities offer the potential for waste-to-energy plants and biogas digesters [9] that would run on MSW. A recent study by Capital Ethiopia suggests that 35 Ethiopian cities have the potential to generate power from waste. The first of these projects is nearing completion in Addis Ababa, in the form of the 50 MW Koshe waste-to-energy power plant at the Reppi landfill.

4.3.1. Cost of electricity from low-carbon energy sources

Comparison of the cost of electricity generation is enabled by examining the by levelized cost of electricity (LCOE), which standardizes the initial capital investment, operation and maintenance costs over the lifetime of the plant. According to the World Energy Council, the LCOE is the price that must be received per unit of output as payment for producing power to reach a specified financial return or, put simply, the price that project must earn per megawatt hour in order to break even (WEC, 2013).

Around the world, the cost of energy generation from renewable sources has significantly declined over time. Improvement in efficiency of conversion and the continually growing market for such technologies are major reasons for the cost reduction. In 2014, the average LCOE for a residential solar PV system was reduced from about $0.38/kWh in 2008 to about $0.14/kWh in 2014 (IRENA, 2015). Decline in cost of power generation, by roughly 60 per cent, has enabled renewable energy resources to be financially competitive, particularly in cities where utility electricity is not dependable and the cost of not having electricity and the cost of running a backup system are high.

[9] The potential for waste water to energy could also be explored.

In areas where feedstocks are available at low cost, biomass-generated electricity can be competitive. Estimates suggest that if biomass power plants are located near biomass sources, such as industry, forestry or agricultural processing plants, and inexpensive gasification technologies are used, then electricity can be generated at costs as low as $0.03/kWh in developing countries. Typical LCOE for biomass-fired power generation projects is between $0.05/kWh and $0.15/kWh (IRENA, 2015).

Table 7 Global Average LCOE from Different Energy-Generating Technologies (WEC, 2013)

Technology	Average LCOE (USD/kWh)	
	2009	2013
Offshore wind	0.095	0.08
Solar PV	0.32	0.135
Biomass		
Landfill gas	0.075	0.06
Incineration	0.135	0.125
Municipal solid waste	0.125	0.11
Gasification	0.15	0.15
Anaerobic digester	0.175	0.13
Hydropower		
Small hydro		0.019 – 0.314
Large hydro		0.024 – 0.302
Coal		
Coal	0.055	0.08
Coal with CO_2 capture and sequestration	0.055	0.15
Combined Cycle Gas Turbine		0.07
Nuclear		0.094

4.3.2. Alternatives to thermal energy

Thermal energy needs in cities can be classified in two distinct subsets. In the households and services sector, thermal energy is needed for cooking and hot water, while in the industrial sector, thermal energy needs are predominantly for product processing and firing. Space heating does not appear to be in high demand in most cases, given Ethiopia’s moderate to warm climate.

4.3.2.1. Industries

In the industrial sector, energy requirements are for thermal energy (direct heat in kilns and ovens, heat for steam and hot water production), for motive power and for electric appliances. Thermal energy requirements take the large share of energy demand in industries, particularly in the large industries such as cement. In the small industry sub-sector, thermal energy requirements are also high (for example, in bakeries), but motive power is very important (in such applications as milling). In the large industries, thermal energy requirements are met by fossil fuels (coal and petroleum coke in cement factories for kilns, furnaces for steam raising in most other industries). In the small industrial sector, the demand for thermal energy is met mostly by electricity and wood (for example, bakeries), which is a concern because wood is sourced from non-sustainably managed sources.

The Mekelle Cement Factory, for example, is one of the heavy industries in Mekelle, consuming much of the electricity capacity of the city. For its thermal energy needs, particularly for clinker firing, it uses coal. The factory recently developed a concept note for the substitution of coal by biomass from agricultural waste. Residue from a sesame farm in the Western Zone of the region contributes more than 570 kilotons annually, with very small or no local use. The Mekelle Cement Factory conducted a feasibility study to substitute 40 per cent of its coal consumption with 10 per cent of the agri-waste from the sesame farm. In doing so, the factory will cut its expense for importation of coal by over $1 million per year and use the savings for collecting and processing of sesame waste, with potential creation of new jobs This initiative would thus make significant social, environmental and financial impacts (Mosobo Cement Factory, 2012).

Cement factories also have potential for electric power generation using waste heat recovery, that is, co-generation. Operation of co-generation plants by generating steam, using waste heat recovery, is a more economical option than direct generation of steam. There is ample scope for this in steel plants and cement factories (Varma & Srinivas, 2015). It is estimated that the Mekelle Cement Factory could double its advantage by coupling a co-generation unit to its biomass-fired system.

4.3.2.2. Households and service sector

Cooking energy in secondary cities is predominantly done through biomass fuels obtained from an unsustainable resource base. Charcoal is the primary cooking fuel in households in most secondary cities, including Mekelle and Diré Dawa. According to the Mekelle Regional Energy and Mines Agency, prices of charcoal are continually increasing because of a mismatch of demand and supply. Demand for cooking fuel is consistently increasing, while fuel has become scarce because of depletion of the biomass resource in the surrounding areas. While the local government has tried to encourage a shift towards electricity, frequent power outages have impeded this shift.

The charcoal price in Mekelle is the highest in the country, with a price of ETB 9.52/kg ($0.45/kg) (Megen Power, 2014). Despite such a high price, households in Mekelle prefer charcoal as a cooking fuel. Thus, it appears that households in cities like Mekelle continue to rely on traditional cooking fuels like solid biomass and charcoal because of their preferences for traditional cooking methods, the lack of reliability of electricity, and lack of access or availability of other clean and affordable alternatives besides electricity.

Several alternative energy sources have been proposed. Ethanol produced from molasses, a by-product from sugar production, is a lower-carbon energy source that is cleaner and safe to use. Supplies can be derived from the developing sugar industry in the region. Briquetted or pelletized biomass from sesame waste can also be a source for clean cooking fuel for households and commercial establishments.

The figure below compares the cost of cooking with different fuels and cook stoves. The comparison considers the efficiency of the cook stoves, the energy in the fuels and the useful energy for cooking. Useful energy is the average energy absorbed by the food during cooking to make it palatable for human consumption, and is independent of the type of fuel and the cook stove used for cooking. The graph shows the maximum price for a certain substitute fuel to break even with the cost of cooking with the baseline fuel. For instance, in Mekelle, to substitute ethanol for similar cooking done on a traditional stove with charcoal purchased at a price of ETB 9.52 ($0.45), the price of ethanol should be ETB 16.70/litre ($0.80/litre). A price any higher than ETB 16.70/litre ($0.80/litre) will cost households more to do the same task. If the substitute fuel is LPG, its price should then be ETB 31.60/kg ($1.50/kg) or less. However, the current price of LPG in Mekelle is over ETB 50/kg ($2.38/kg). Similarly, to cook with electricity, an electricity price as high as ETB 2.60/kWh ($0.12/kWh) is still feasible. Current average domestic tariff for cooking from the utility is ETB 0.60/kWh ($0.029/kWh). Energy efficiency also plays an important role in reducing cost of cooking in the households. Comparison of cook stoves that use the same fuel but with different performance shows the cost advantage of using energy-efficient cook stoves.

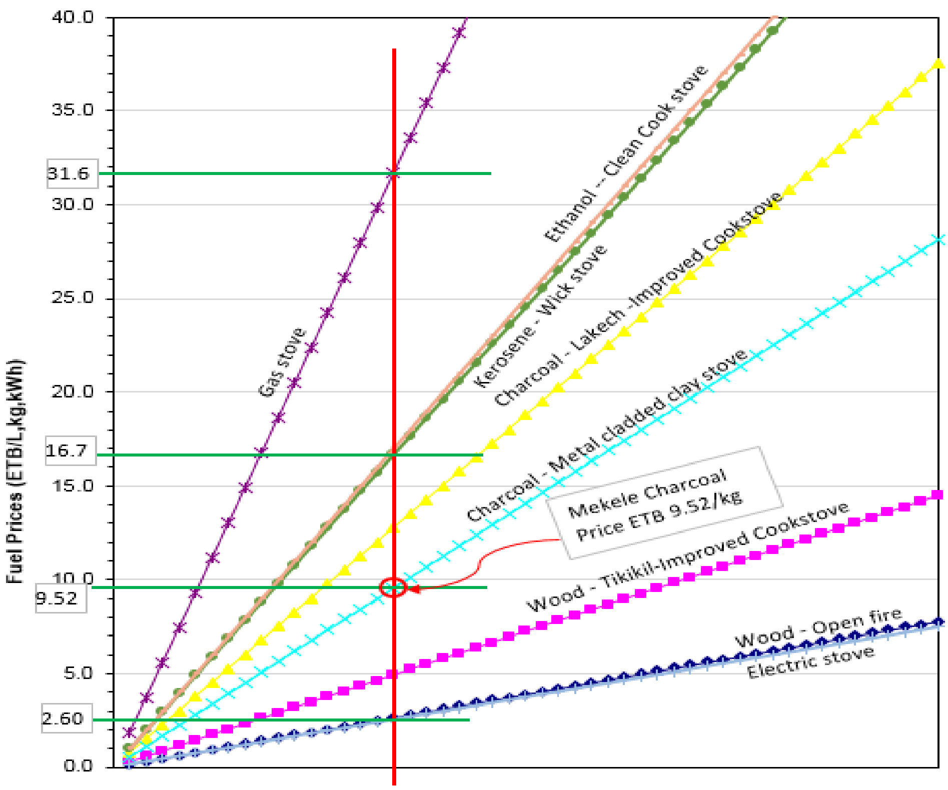

Figure 32 Comparison of cost of cooking with different fuels and cook stoves based on useful energy terms

Water heating in cities typically relies on electricity or biomass fuels. Both energy sources are unreliable, with limited or intermittent availability. Water heating demand in households and commercial sectors, such as hotels, unfortunately coincides with the evening or morning peak electricity demand, stressing the capacity of power infrastructure. Use of solar water heaters would be the most economically feasible technology for domestic, commercial and, in some cases, industrial hot water demands. Shifting away from biomass and electricity for water heating to solar could ease the burden on forests and alleviate the demand on scarce electricity that could be used to power heavy industries.

There are challenges and barriers that cities need to overcome to successfully address energy demands of city dwellers in the face of climate change impacts. These challenges are related to existing policies and regulations that do not internalize climate resilience in development planning, limited technical knowledge and skills in low-carbon energy technologies, lack of sufficient institutional support, and lack of financing options. Cities may need to advocate the need for alternative, clean, low-carbon, climate-resilient energy to the national government so that national policies would empower cities to become resilient and manage their energy requirements. The costs and impacts of various renewable energy technology options are covered in more detail in the following section.

4.4. Low-carbon energy co-benefits, costs and benefits

There are significant societal benefits that can be achieved from the proposed transition to low-carbon energy in secondary cities in Ethiopia. Some of these are discussed below.

4.4.1. Improved population health

An understanding of public health and related socioeconomic impacts associated with the use and combustion of solid biomass fuels such as wood and charcoal can help in evaluating the benefits of transitioning to cleaner low-carbon energy fuels in secondary cities.

In terms of morbidity, according to the World Lung Foundation, lung diseases such as tuberculosis (TB), acute respiratory infections, chronic obstructive lung disease, lung cancer and asthma are major public health problems in Ethiopia. Rates of acute respiratory infections in Ethiopia are among the highest in the world, and rates of asthma, chronic obstructive pulmonary disease (COPD) and lung cancer are rising. The burden of chronic lung disease (especially in women) from exposure to indoor air pollution (IAP) and outdoor air pollution is substantial and troubling (World Lung Foundation, 2016). The prevalence of asthma in Ethiopia is 9.1 per cent, while neighbouring Kenya's stands at 15.8 per cent, and Mozambique's at 13.3 per cent (van Gemert, et al., 2011).

Exposure to IAP from the combustion of solid fuels has been hypothesized to be a major cause of several diseases, including acute respiratory infections (ARI), COPD, asthma, diseases of the eye such as cataract and blindness, and low birth weight and associated neonatal conditions (because of maternal exposure during pregnancy). Global mortality from IAP was estimated at 1.5 million to 2.0 million deaths in 2000.

According to the World Health Organization's (WHO's) World Health Report, ARI is known to be the most common cause of illness and mortality in children in the developing world (Pitt, et al., 2010). The Centre for Disease Control (CDC) in Ethiopia ranks lower respiratory infections first among the top 10 causes of death in the country, accounting for up to 10 per cent of deaths (CDC, 2016). A study by Misganaw et al. (2012), on patterns of mortality in public and private hospitals of Addis Ababa in Ethiopia, revealed that 14 per cent of deaths (6,618 out of a total of 47,153) recorded between 2002 and 2008 were the result of respiratory infections (3,523 - Table 8 below). Respiratory infections featured among the five leading deaths for nearly 56 per cent of the male deaths and 68 per cent of the female deaths recorded between 2002 and 2008. According to the study, a marginally higher proportion of females (8 per cent) than males (7 per cent) died from chronic respiratory infections, and similar percentages from respiratory diseases (Misganaw, et al., 2012).

Table 8 Cause of mortality distribution by gender in public and private hospitals, Addis Ababa, Ethiopia, 2002-2010 (Misganaw, et al., 2012)

Cause of Death	Number	Percent [a] (95% CI) [b]		
		Male	Female	Total
I. Group I	**27,568**	**52 (51.4 - 52.6)**	**67 (66.4-67.6)**	**59 (58.6-59.4)**
A. HIV/AIDS	5350	10 (9.6-10.4)	13 (12.5-13.5)	11 (10.7-11.3)
B. Tuberculosis	5,065	11	11	11 (10.7-11.3)
C. Respiratory Infections	3523	7	8	8 (7.8-8.2)
D. Diarrheal Disease	417	1	1	1
E. Meningitis	1139	2	2	2
F. Maternal Conditions	1299	0	6	3
G. Conditions arising during perinatal period	9337	17 (16.6-17.4)	24 (23.4-24.6)	20 (19.6-20.4)
- Low Birth Weight	2069	4	5	4
- Still Birth	7614	13 (12.6-13.4)	20 (19.4-20.6)	16 (15.7-16.3)
H. Nutritional Deficiency	876	2	2	2
II. Group II	**14,683**	**30 (29.5-30.5)**	**32(31.4-32.6)**	**31 (30.6-31.4)**
A. Malignant neoplasm	1,531	3 (2.8-3.2)	4 (3.7-4.3)	3 (2.8-3.2)
B. Diabetes Mellitus	801	2	2	2
C. Neuropsychiatric conditions	908	2	2	2
D. Cardiovascular diseases	5,375	11 (10.6-11.4)	12 (11.6-12.4)	11 (10.7-11.3)
Hypertensive heart disease	1047	2	2	2
Cerebrovascular disease	1223	3	3	3
Congestive Heart Failure	1267	2	3	3
Ischemic Heart Disease	1726	4	4	4
E. Respiratory diseases	3095	6 (5.7-6.3)	7 (6.6-7.4)	7 (6.6-7.4)
F. Digestive Diseases	2617	6	5	6
Chronic Liver Disease	987	2	2	2
G. Genitourinary Disease	1100	2	2	2
III. Group III	**5,776**	**17 (16.6-17.4)**	**6 (5.7-6.3)**	**12 (11.7-12.3)**
A. Unintentional	2527	7	3	5
Road traffic accidents	1915	6 (5.7-6.3)	2(1.8-2.2)	4(3.8-4.2)
B. Intentional (Suicide…)	566	2	0	1
Total	47,153	100 (26,928)	100 (20,225)	100

* Totals may not add precisely.
[a] Values above one rounded to nearest whole number and values less than one were not reported.
[b] 95% confidence intervals have been provided for major categories and for the leading causes of death.

Acute lower respiratory infection, the most serious type of ARI, accounts for 20 per cent of the annual deaths of children under five, with nearly all of these deaths occurring in the developing countries. Not only is ARI a leading cause of deaths in developing countries, but exposure to smoke during childhood can potentially have long-term consequences. Lungs typically grow to full capacity during the teen years. The deficits in the lung function of younger children caused by air pollution are unlikely to be made up as children age even if their exposure levels decline dramatically, and the greatest effects of these pollution-related childhood deficits may occur later in life (Gauderman, 2004).

Like many household chores, cooking is a daily household activity traditionally performed by women in Ethiopia, and children are often found in the company of their mothers/women. Given the widespread use of solid biomass fuels for cooking at households, women and children are highly exposed to the IAP and the associated respiratory as well as physical health risks. Given the slum settings in the secondary cities of Ethiopia, the prevalence of poorly ventilated households lead to a marked increase in the health risks associated with IAP.

While all Ethiopia's secondary cities are presently linked to the power grid and power tariffs are affordable, most households, including those connected to the electricity supply grid, still use solid biomass fuels including wood and charcoal. Households prefer solid biomass fuels for traditional cooking, citing better taste of the food. Given the high prevalence of wood and charcoal for household cooking (74 per cent of urban residents, 68 per cent and 80 per cent of Mekelle and Diré Dawa urban populations; CSA, 2012), a significant proportion of the Ethiopian population (especially women and children) are at risk of the impacts associated with fetching firewood as well as IAP. Other risks that accompany use of unclean biomass fuels include fire hazards, eye diseases from use of poor lighting to study/read, health risks from handling of animal waste (cow dung) as sources of fuel, and loss of lives from fires and respiratory diseases.

4.4.2. Gender justice

Given that safety has been highlighted as a key goal in Ethiopia's National Energy Policy, it is vital to promote access to energy services that are safe. Given that women and children face significant risk, it is essential that decisionmakers/policies around energy options prioritize the health of women and children to avert the health risks and deaths.

As such, national policies as well as decision-making processes should always seek to promote the interests of women and children who are at greatest risk within households. The public health implications of energy services on the population are significant and must be given due attention. It is important that policies and decisions regarding energy options consider ensuring affordability and promotion of cleaner energy options in households that would avert the health impacts of IAP.

To promote equitable and socially inclusive development, it is significant to understand the role that renewable energy sources have. Women in Ethiopia spend a significant amount of time cooking and develop health complications that limit their productivity and ability to contribute to household income. The use of improved fuel sources, and more efficient cook stoves and cooking practices at the household level, would significantly improve the livelihoods of households, especially for women, who would be healthier and spend less time cooking, creating time for other income-generating activities.

4.4.3. Reduced environmental degradation

A shift from biomass-based energy in Ethiopia towards improved energy sources, particularly low-carbon sources, would have beneficial environmental impacts. Decreased fuel collection of firewood would allow natural vegetative cover to increase, and allow trees and shrubs to help the land's drainage and absorptive and drainage capacity to increase during rains (simultaneously decreasing erosion). With less reliance on animal dung for thermal energy, more dung could be allowed to fertilize cultivable lands, restoring fertility and soil nutrition through natural means.

4.4.4. Broad-based socio-economic development

Improving energy services for households in Ethiopia would have many significant socioeconomic impacts on communities. These include the following:

- Time for families to spend together and for leisure; reliance on alternative energy sources that are more easily accessible than wood fuel, biomass and so on., requires laborious collection.
- Increased opportunities for education for children and information for adults; with adequate and healthier lighting, children can read/do homework without straining their eyes on poor kerosene or wood lighting. Adults may be able to attend literacy classes in the evenings. Families could have reliable energy to power their radios and have improved access to information.
- Improved energy sources such as solar can lead to improved water supply to cities through cheaper and more affordable pumping; water can be more accessible with solar water pumps; this contrasts with transporting water on foot, which may take several hours a day.
- Increased productivity of households and potential increase in incomes from improved lighting and energy sources at the household level, as well as more time saved from the elimination of distances travelled in search of wood and water.
- Improved opportunities for employment for individuals, such as, maintenance and installation jobs.
- Extended operating hours for local businesses because of prolonged lighting, which increases incomes.

- Reduced travel- and water-carrying burden especially for women. This saves/creates time for women to join/start income-generating activities, improving the household livelihoods, especially for women-headed households.

It is clear that low-carbon energy resources offer multiple co-benefits and inclusive growth by potentially increasing population health, gender justice, and broad-based socio-economic development and by reducing environmental degradation.

4.5. Country comparisons

To better understand the energy context in secondary cities, and for national- and city-level planners to gain insights on clean energy options that could be explored, comparative examples from Mozambique, Uganda and Kenya are highlighted below.

The case studies of Mozambique, Uganda and Kenya are structured as follows: First, national energy resources are mapped, in order to familiarize the reader with the case study context, as well as to show similarities and contrasts with the Ethiopian context. Further, governmental strategies on renewable energies are discussed, including how those are expected to boost development, particularly in rural hubs. Finally, examples of sustainable solutions for off-grid settings developed in each country are highlighted. These are meant to inform the development of such solutions in Ethiopia.

In each case, a comparison between Ethiopia and the case study country is given, highlighting commons trends in energy access, particularly in urban settings, as well as the salient differences and comparative advantages of regulatory and support mechanisms in each case. Ultimately, this section offers some lessons learned from countries in a similar regional context, with largely unexploited sources of renewable energy.

4.5.1. Mozambique

Like Ethiopia, Mozambique has abundant renewable energy resources; however, the reach of the national grid is much less advanced than in Ethiopia, so the case for off-grid solutions is somewhat more compelling. Ethiopia, given its limited effective access to electricity, could learn from the dual approach that Mozambique has adopted of extending the transmission network while also developing off-grid solutions in the form of mini-grids and stand-alone systems (comprising solar, biogas and mini-hydro) in smaller urban centres. Although in early stages of advancement, with most of the funding still being invested in the extension of the centralized grid, the decentralized approach is seeing some success. A separate entity from the main power utility, the National Fund for Rural Electrification (FUNAE), is responsible for implementing decentralized access to electricity. In both countries, increasing access to electricity will allow for beneficiation of agricultural products and potential job creation through the development and implementation of low-carbon energy technologies.

4.5.1.1. Energy resources

Mozambique is similar to Ethiopia in that it is endowed with significant renewable energy sources (hydro, biomass, solar, wind, geothermal and waves). Unlike Ethiopia, it also has fossil fuels (natural gas and coal). Despite this endowment, Mozambique's national grid serves only about 18 per cent of the population and is subject to high transmission and distribution losses (25 per cent) (IRENA, 2012). The rural regions of Mozambique are poorly served by electricity infrastructures, which limits their ability to process agricultural products and generate a sustainable income. Mozambicans are among the population that consumes the least electricity per capita in the world (Hankins, 2009). Instead, forest resources represent more than 85 per cent of total domestic energy requirements (95 per cent in rural areas).

The energy sector is, however, key to the Mozambican economy, as the country's energy exports make up a large share of total foreign exchange earnings. Indeed, Mozambique is a powerhouse for the southern Africa region, exporting low-priced electricity from Cahora Bassa Hydropower Plant, one of the largest dams on the continent, and attracts investments in "mega-projects" such as smelting plants and refineries (Hankins, 2009).

In the coming years, Mozambique will face a higher national demand for energy. Indeed, the Mozambican economy is growing at a high rate (7.6 per cent real GDP growth in 2014) and is expected to continue growing (African Development Bank, 2014). The country's economy is transforming and slowly industrializing. Moreover, the demand from currently off-grid regions will also rise, as the government aims to intensify electrification of the country; indeed, the national power company, Electricidade de Mozambique, (EdM) is leading an electrification programme that currently creates 100,000 new connections yearly. Part of the programme is a rural electrification program, largely funded by international donors. Finally, the Mozambican population is migrating from rural to urban areas (Maputo and secondary cities), thereby increasing the demand for energy in electrified areas. The growth of secondary cities, such as Matola (Maputo Province), Beira (Sofala Province) and Napula (Nampula Province),[10] influences the Mozambican energy national context.

To respond to this growing national demand and to take advantage of the opportunities from foreign demand, Mozambique has the potential to increase its energy production, not only through its coal and natural gas resources, but also through exploitation of its currently under-exploited renewable energy resources. The Mozambique's Minister of Energy is aware of the potential of the country to use renewable energy to satisfy national and foreign consumption. A challenge for Mozambique is now to ensure that energy solutions serve the whole country, supporting emerging cities and communities dispersed throughout the country.

4.5.1.2. Future cities and energy

Mozambique is one of the major renewable power producers in Africa; hydropower is the main source of power generation in the country, while solar panels, set up in a decentralized manner throughout the country, provide electricity to millions of Mozambicans in rural areas. By further exploiting the variety of renewable energy resources available in the country and diversifying its energy resources, Mozambique would ensure the long-term sustainability of the supply, and thereby achieve a higher resilience of secondary cities, as well as better access to energy throughout the country. Further, the production of energy from renewable sources is competitive toward the conventional resources, thanks to Mozambique's access to concessional financing.

Mozambique is endowed with numerous natural resources that can be converted into energy. The country has large rivers, thermal springs, and strong winds in the highlands and receives

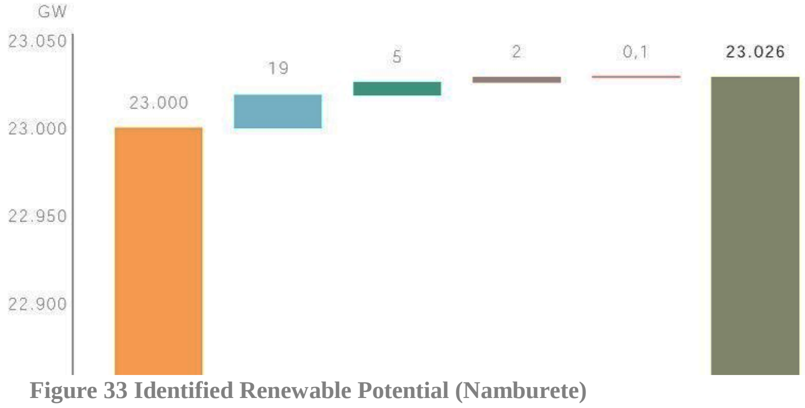

Figure 33 Identified Renewable Potential (Namburete)

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[10] Those cities are considered as secondary cities for the size of their population (between 500,000 to 3 million inhabitants) and their lack of international aura. Matola counted 675,422 inhabitants in 2007; Beira counted 546,000 inhabitants by 2006; Napula counted 477,900 inhabitants according to the 2007 census. They are secondary to the prime and capital city, Maputo. Other cities count roughly between 100,000 and 250,000 inhabitants, such as Chimoio (Manica province), Nacala (Nampula), Quelimane (Zambezia), Tete (Tete), Lichinga (Niassa), Pemba (Cabe Delgado), Gurue (Zambezia), Xai-Xai (Gaza), Maxixe (Inhambane), and Cuamba (Niassa).

constant sun and has optimal conditions for sugar cane plantations. The potential of the various sources of renewable energy exceed 23,000 GW, the majority from solar, followed by hydro (19 GW), wind and biomass.

Solar energy is the most abundant renewable resource in Mozambique, with a potential of 23,000 GW. Exploiting it can be at reasonable cost if initial financing is obtained. **Water** is the resource favoured by the Mozambican government, as hydropower projects are the least costly. The government has identified hydropower projects (for more than 5,6 GW) as priority projects. New large dams will be created on the Zambezi River, as well as medium-size projects in other small rivers. **Wind** energy can also be obtained at competitive costs throughout the country, especially in the South. **Biomass** projects are also envisaged in Mozambique (forest biomass, industrial and agro-industrial waste, residual bagasse from the sugar industry and so on); those, despite their higher cost, would have the advantage of creating employment opportunities in rural areas. Finally, **geothermal** energy is another option, though it bears higher costs and risks. With its massive coast, Mozambique can also utilize the potential of **wave** energy (Namburete, n.d.).

To serve emerging cities in remote regions, Mozambique should also expand its transmission infrastructures to those regions. With the current transmission infrastructures, most of the power produced by Mozambique is exported to South Africa before being re-imported at higher cost (Hankins, 2009). The Ministry of Energy has identified numerous potential projects to exploit renewable energy throughout the country, as shown in Figure 34. To enhance the resilience of emerging cities, Mozambique should prioritize projects that could provide energy for those cities.

4.5.1.3. Sustainable solutions for urban off-grid settings: Mozambican examples

The government of Mozambique, just like most governments in Africa including in Ethiopia, aims at electrifying the country using predominantly grid-based technologies (Hankins, 2009). Major cities in Mozambique are provided electricity through a grid managed by EdM, the national power company. Access to electricity through this "centralized" power production is estimated to be around 18 per cent (IRENA, 2012).

However, numerous areas of this wide country, mostly rural areas but also small urban centres, are not connected to the grid yet. The north of the country is particularly isolated in that regard (Hankins, 2009). Poor access to electricity has adverse developmental consequences and triggers movement of population towards electricity amenities. Despite the government's ambitions to extend the grid to reach more end-users, this extension is not without its challenges (IRENA, 2012). Mozambique's large and sparsely populated territory contributes to the difficulties to reach each inhabitant. According to the International Renewable Energy Agency, large regions of Mozambique will not be reached by the grid in the short to medium term (IRENA, 2012).

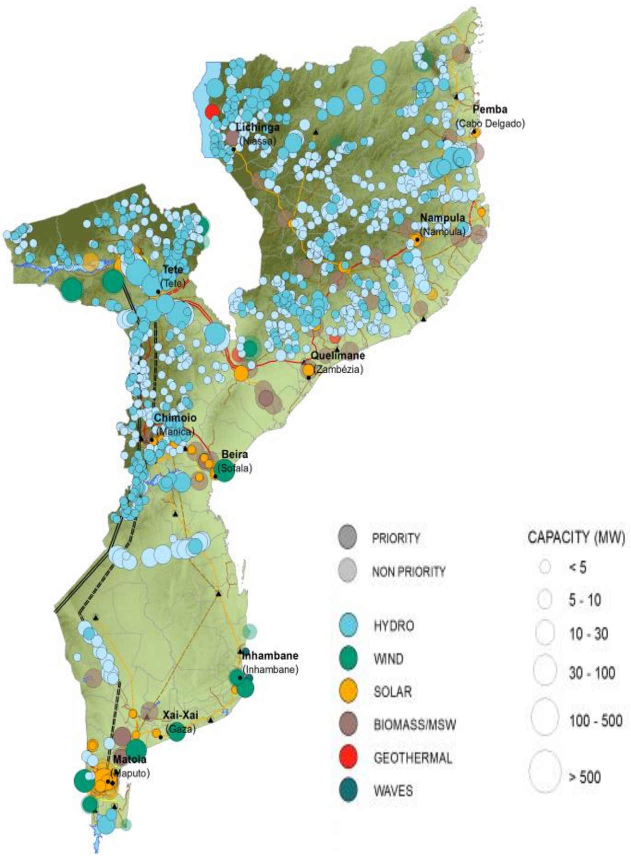

Figure 34 Locations of Renewable Potential (Namburete)

Off-grid electricity is thus a much-needed alternative. Such off-grid electrification in Mozambique is done in two different ways: either using mini-grids (this is especially relevant in providing electricity to towns that are distant from the grid); or using small stand-alone systems. Those are installed directly on the premises of the end-users: institutions, villages and businesses (Hankins, 2009). While EdM does not have the mandate to work on isolated grids, FUNAE has an important role to play. Indeed, this autonomous government agency is responsible for providing access to modern energy services and implementing off-grid electrification in rural and isolated communities.

Evidence shows that the most cost-effective sources of power for mini-grids in remote parts of Mozambique are biogas units, biomass gasifiers and micro-hydro stations, as biomass (including forest/agricultural waste) and water are abundant in the country (Hankins, 2009) (IRENA, 2012). Solar PV and wind for mini-grids are also cost effective, especially where the costs of transporting fuels are high. For facilities requiring a low level of power, corresponding to less than 3 kW, pico-hydro, solar PV and wind can be the most effective options; such facilities include isolated schools, clinics, government facilities and households (Hankins, 2009).

FUNAE's approach to rural electrification reflects those findings, focusing on solar energy, biomass energy, and mini-hydropower. The fund successfully implemented a number of off-grid projects. The following projects, all coordinated by FUNAE, illustrate the efforts put into decentralization of the electricity supply. All of those projects are expected to stimulate social and economic development. FUNAE, together with its implementing partner, is constructing three PV stations in the Niassa Province (Mavago, Mecula and Muembe). The stations will generate energy to benefit about 29,500 people through the electrification of 2,401 households, 10 primary and secondary schools and 3 health centres. To that end, low-voltage power distribution grids will also be constructed (FUNAE, 2016). FUNAE is working on the electrification of numerous districts in the Sofala Province through a set of solar PV installations. The electricity produced should cover the needs of 254 households, as well as of other local infrastructures such as schools, health centres, police stations and shops (FUNAE, 2016). Finally, as another example of a decentralized project, but with another renewable resource, water, FUNAE is working on the construction of the Rotanda Mini-hydro power (Manica Province). The infrastructure is to provide electricity to the 13,000 inhabitants of the Rotanda Village (630 Kw of energy).

Those investments in off-grid electricity solutions are scarce; most investments to improve access to electricity in the country are made to extend the grid; as an illustration, during the 2006-2008 period, EdM made more than 250,000 electricity connections to the grid; only a few thousand were made using mini-grid and stand-alone solutions (Hankins, 2009). While grid-based electricity does present some advantages over other decentralized technologies, such as lower connection costs[11] and better-quality power supply (Hankins, 2009), it does not yet meet the needs of all Mozambicans. Off-grid electricity supply is needed to complement the grid. While national access to electricity is estimated for off-grid around 11 per cent, the resources present in Mozambique have the potential to bring this number up (EDM , 2011).

[11] However, the cost per connection with stand-alone systems is much higher than through the electricity grid; it is estimated to reach over $1,500 per connection, while it is of only $800 through the grid (higher unit prices for electricity than on-grid approaches. Mark Hankins, A Renewable Energy Plan for Mozambique, September 2009

4.5.2. Uganda

Access and use of electricity in Uganda are even lower than in Ethiopia, yet it shares a similar dependence on biomass for its energy requirements, and increasing energy demand (from sustained economic growth) coupled with rural-urban migration. Current electricity supply in the form of hydropower generated from the waters of Lake Victoria is the main source of electric power. It is a vulnerable resource that depends heavily on the water levels of the lake, and affects reliability of supply to the capital, Kampala, and a number of secondary cities. The impetus to diversify the supply of electricity is strong and mirrors the case in Ethiopia. Among secondary cities, the city of Kasese shows what is possible when a city has a degree of autonomy to embark on an innovative and bold pursuit of a sustainable energy supply for its citizens. The approach adopted by Kasese offers a positive lesson for what can be achieved, not only for Ethiopian cities, but cities across the developing world. With the right combination of energy solutions, and strong partnerships at the local level, secondary cities can go a long way to increasing their own energy security; however, they need to be aware (as described in the case of Mozambique) that reliable, safe and affordable energy amenities may increase the level of migration to that city, and additional growth needs to be factored in to the planning of the city.

4.5.2.1. Energy resources

The main source of primary energy for the Ugandan population is biomass, that is, firewood, charcoal, crop residues (90 per cent). According to the Ministry of Energy, oil products are used mainly in the transport sector and represent 9.7 per cent of the national energy balance; electricity comes last, with only 1.4 per cent of the balance (Ministry of Energy and Minerals Development, n.d.). Access to electricity in the country is very low (about 15 per cent in 2015), and Ugandans' per-capita electricity consumption is one of the world's lowest (215 kWh per capita per year) (Ojambo, 2015). In Uganda, 84 per cent of electricity is generated by hydropower plants: The Nalubaale Power Station at Owens Dam (which, until 2002, produced all of Uganda's electricity) and the Kiira Power Station.

The national demand for electricity has been continually rising at an average of 10 per cent (22.7 per cent at its peak) per annum in the last decade and is likely to continue rising in the years to come. This increased demand is the result of sustained economic growth (around 6 per cent in the past decade) (Ministry of Energy and Minerals Development, n.d.). Further, electrification of the country is advancing; since 2002, the number of electricity connections is reported to have increased by 50 per cent. Finally, the movement of population form rural to urban centres has increased the demand for electricity in urban hubs.

4.5.2.2. Future cities and energy

Uganda has been challenged to respond to that growing energy demand, and to supply the population accordingly. Lake Victoria's runs through all Ugandan hydropower plants, and when the lake's levels are low the country faces electricity shortages and prolonged blackouts, as was the case in 2005 and 2006 (Gatsiounis, 2011). Setbacks in supply do affect the resilience of urban centres, certainly the capital Kampala, but also secondary cities such as Kira, Mbarara, Mukono, Gulu, Nansana, Masaka, Kasese and Hoima.[12]

To make its economy and urban centres increasingly resilient, Uganda needs to increase and diversify its production of energy. The Ministry of Energy successfully worked on boosting the country's production; by October 2015, the generation capacity of the country reached 852 MW, a supply largely surpassing the demand (540 megawatts at peak) (Nakaweesi, 2015). Moreover, in 2013, the government began construction of two new hydropower stations, the Isimba Power Station (183 MW)[13] and the Karuma Power Station (600 MW) and high-voltage transmission lines.[14] In addition, in May 2015, Uganda connected six mini-hydropower plants to the national electricity grid, supplying about 65 MW.

Uganda has also seized opportunities to diversify its national energy pool, opening three thermal power plants (running on diesel) in 2005. Further, the Ministry of Energy is planning to open two solar power stations (10 MW) by the end of 2015: the Tororo Solar Power Station and Soroti Solar Power Station. Uganda's ambition is to reach a total generating capacity of at least 1,500 MW by the end of 2018.

4.5.2.3. Sustainable solutions for urban off-grid settings: A Ugandan example

While the government of Uganda aims at extending the national electricity grid to major urban and peri-urban areas, it has limited resources. Some urban centres are thus still isolated from the grid. To gain access to electricity and to the developmental opportunities associated with

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[12] Secondary cities are defined by the size of their population (approx. between 500,000 to 3 million inhabitants) and their lack of international aura. Secondary cities in Uganda are relatively small; Kira counts 313,761 inhabitants, Mbarara, Mukono, Gulu, Nansana, Masaka, Kasese, Hoima count between 100,000 and 200,000 inhabitants (2014 census population count).

[13] Secondary cities are defined by the size of their population (approx. between 500,000 to 3 million inhabitants) and their lack of international aura. Secondary cities in Uganda are relatively small; Kira counts 313,761 inhabitants, Mbarara, Mukono, Gulu, Nansana, Masaka, Kasese, Hoima count between 100,000 and 200,000 inhabitants (2014 census population count).

[14] Secondary cities are defined by the size of their population (approx. between 500,000 to 3 million inhabitants) and their lack of international aura. Secondary cities in Uganda are relatively small; Kira counts 313,761 inhabitants, Mbarara, Mukono, Gulu, Nansana, Masaka, Kasese, Hoima count between 100,000 and 200,000 inhabitants (2014 census population count).

it, some Ugandan cities have experimented with the use of off-grid renewable or low-carbon energy sources.

As an example, the city of Kasese (126,000 inhabitants), together with its district, embarked on an ambitious program to shift to 100 per cent renewable energy by 2020 (Seleverio & Kime, 2015). In 2015, only 7.6 per cent of the 135,000 households in the Kasese district had access to the national electricity grid. The city of Kasese, through its mayor Godfrey Baluku Kime, established partnerships with universities, businesses and NGOs to develop off-grid sustainable energy solutions, such as solar lightning and charging systems. Through the development of such solutions, many have gained access to electricity. By September 2015, renewable energy systems supplied about 26.8 per cent of the total 146,000 households in the Kasese district. Moreover, the Kasese community shifted its behaviour; before that program, the local population relied on charcoal and firewood for cooking (97 per cent of locals) and on inefficient kerosene for domestic electricity production (85 per cent). Because of the programme, the community is increasingly using solar energy for lighting in houses and businesses, and biogas for cooking. The development of off-grid sustainable solutions has not only improved living standards of the locals (increased electrification, more cost-effective and safer use of energy); it has also reduced the city's environmental impact by diminishing deforestation rates and strengthened the local economy by encouraging an increased number of green economy business and by boosting the tourism industry.

4.5.3. Kenya

Kenya shares some regional similarities with Ethiopia, and although its current initiatives around low-carbon energy sources are not specifically targeted at the city level, there are some proactive approaches adopted to meet increasing electricity demand and facilitate a transition to more modern fuels while alleviating poverty. In essence, Kenya has taken steps to devolve the responsibility for the provision of energy services to sub-national governments, and to share key roles between national and country governments. Kenya has also created tax breaks for renewable energy and energy efficiency technologies, and is providing feed-in-tariffs for wind energy, as well as a streamlined approval system process for renewable energy projects. The initiatives pave the way for more private sector involvement in the supply of energy, which Ethiopia could emulate.

4.5.3.1. Energy resources

Kenya has been perceived as the leading and commercial economy in Central and Eastern Africa, graduating to a Middle-Income Country recently (World Bank). However, despite the real growth in the economy over the last 10 years, the Gini coefficient, indicating income inequality, is high and poverty remains widespread especially in rural areas. In 2009, only 25 per cent of Kenyans had access to electricity, with only 5 per cent of rural population and 50 per cent of the urban population being electrified (IMF, 2010).

The government is moving fast to redress this imbalance, which has been recognized as a major handicap to industrial and commercial development. In 1994, the government produced its first Energy Sector Policy Framework, which saw the separation of policy functions from commercial operations, and liberalized tariffs to reflect market conditions. Kenya Power Company, the national state agency, asserts that electrification has jumped from 25 per cent in 2009 to 50 per cent of the population, with generation capacity of 2,300 MW of which one-quarter (658 MW) is produced by 10 private sector IPPs. Coverage is expected to reach 70 per cent at the end of 2017, with universal access by 2020, requiring a doubling of power generation capacity to 5,000 MW (Kenya Power, n.d.).

Figure 35 Electrification progress and targets in Kenya

According to Practical Action, biomass energy provides 68 per cent of Kenya's national energy requirements (Practical Action, 2010). In 2000, Kenya was reported to use 34.3 million tonnes of biomass for fuel, of which 15.1 million was in the form of fuelwood and 16.5 million tonnes of wood for charcoal processed in kilns with only 10 per cent efficiency. Because of a moratorium on cutting down trees, charcoal is either produced illegally in the country or imported from neighbouring countries. By 1997, the proportions were estimated to be 90 per cent wood fuel, 5 per cent for industrial feedstock and another 5 per cent for poles and posts.

A more comprehensive and recent study aimed at identifying how Kenya can benefit from and use the climate change REDD+ program found that Kenya has a wood supply potential of 31.4 million m^3 against a national demand of 41.7 million m^3; hence, a current deficit of 10.3 million m^3. A surprising feature is the fact that supply of timber and poles now exceeds the market's demand, probably because of the highly successful commercial plantation and government reforestation program, but this is instead used up through continued demand for firewood and charcoal.

Table 9 Supply and demand of timber, fuelwood and charcoal

	Timber	Poles	Fire wood	Charcoal	Total
Supply	7.4	3.0	13.6	7.4	31.4
Demand	5.3	1.4	18.7	16.3	41.7
Excess (Deficit)	1.9	1.6	(5.1)	(9.1)	(10.3)

Forecasts for a 20-year period indicate a 20 per cent increase in supply and 21.6 per cent increase in demand by the year 2032, which signifies a gradually increasing deficit (MoEWNR, 2013).

According to the Ministry for Energy, forestry and agro-industry residues have the potential to generate 300 MW, including co-generation using sugarcane bagasse of 193 MW. Mumias Sugar Company, for example, generates 35 MW of electricity, out of which 26 MW is fed into to the national grid. Other sugar companies are developing plans for similar value-added investments.

According to the ministry, 25 per cent of Kenya has excellent wind regime areas, particularly in the northwest t of the country (Marsabit and Turkana districts) and the edges of the Rift Valley, with average wind speeds above 9 m/s at 50 m height. The coast has adequate but lower wind speeds of about 5-7 m/s at 50 m height. Many other local mountain spots offer favourable wind conditions for wind energy.

The main challenge is limited knowledge of the Kenyan wind resource. Although the Ministry of Energy developed a Wind Atlas in 2008 using data from 35 meteorological stations spread throughout the country, the information gathered is not adequate to give detailed resolution because of the sparse station network. To augment the information contained in the Wind Atlas, the Ministry of Energy has installed 55 wind masts and data loggers to collect site-specific data for promising wind farm locations. As a result, 80-100 small wind turbines have been installed, often as part of a photo-voltaic/wind-hybrid system with battery storage. Most of these wind turbines are imported, although a few Kenyan companies have recently started locally manufacturing wind turbines ranging from 150 W to 6 kW, with 50 such turbines installed to date.

4.5.3.2. Future cities and energy

Kenya has tried to reduce the cost of access to more modern energy sources, and has been running 14 rural energy centres distributed across the country to serve as demonstration centres to catalyse uptake of renewable and modern energy services.

To enhance delivery of services and reduce regional imbalances in development, Kenyans voted for a new Constitution in 2010 that saw the establishment of 47 county governments in 2013. The Energy Policy and Energy Bill, currently awaiting parliamentary approval, is expected to align the policy and regulatory framework of the sector with the 2010 Constitution's requirements for devolution of electricity services and greater accountability in the sector. The key change will include an obligation for the national and county governments to provide affordable energy services to all citizens, while sharing roles in electricity planning, development, services, and regulation between the two levels of governments national and county. The new law is expected to enhance competitiveness in the process for licensing of renewable energy and natural resources, while opening up access over transmission and distribution networks.

The Feed-in Tariff (FiT) Policy provides a fixed tariff not exceeding $0.12 per kWh for wind-generated electricity. The tariff applies to individual wind farms whose effective generation capacity is above 500 kW and does not exceed 100 MW. As a result, there has been a lot of interest among potential investors to exploit the resource. The government has approved 20 applications from the private sector with a total capacity of 1,000 MW, with a further 300 MW currently under negotiation.

The Ministry of Energy set up a very simplified website (www.renewableenergy.go.ke) to accelerate the planning process for private sector and other investors that wish to undertake power development. Once the investor has registered a company and acquired the land for the installation, the following process is undertaken:

- Step 1: Approval of Expression of Interest.

- Step 2: Kenya Civil Aviation Authority Licence, an Environmental Impact Assessment Licence; Water Abstraction Permit; Geothermal Resource and Exploration Licences.
- Step 3: Feed-in Tariff Power Purchase Agreement.
- Step 4: Approval for Change of Land Use.

For off-grid power, an additional permit (below 3 MW) or a production licence (above 3 MW) and a supply/distribution licence are required.

4.5.3.3. Sustainable solutions to incentivize the uptake of renewable energy: Kenyan example

Fiscal measures have been introduced that allow tax exemption for renewable energy products. In the 1990s, Government of Kenya removed all taxes from PV panels, batteries, inverters and all solar energy products. In the 2010/2011 financial year, it extended the exemption to efficient (LED) lighting. Sensitive to the fact the poor people in both rural and urban areas depend on kerosene for lighting and cooking, the government lowered taxes to 3 per cent below that of petroleum products, such as diesel.

4.6. Conclusions

Several low-carbon energy sources have significant potential in Ethiopia, and can be tapped and developed to meet growing energy demand, particularly in urban areas. Currently, Ethiopia is using less than 10 per cent of its hydro-energy potential, and less than 1 per cent of its wind and solar energy potential. There is ample room for growth for both intermittent renewables such as these, as well as baseload power generation from renewables like geothermal. In the urban context, there is scope for increasing reliance on waste-to-energy power plants.

While the competitiveness of renewables in Ethiopia vis-à-vis the existing power mix is difficult to gauge, given a paucity of publicly accessible data on LCOE and subsidy structures, global trends suggest that renewables are becoming steadily and substantially cheaper, and thus low-carbon energy solutions may be feasible alternatives even from a financial point of view. Co-benefits of low-carbon energy that are difficult to monetize but nevertheless remain important strengths of renewables, including improved public health indicators, gender equity, decreased environmental degradation, and broader socio-economic opportunities.

Ethiopia is not alone in exploring the potential of low-carbon energy in the context of growing cities. Mozambique has seen initial success in its growing off-grid generation programme; Uganda is home to a city piloting the effort to become “100 per cent renewable”; and Kenya is actively attracting IPPs with its feed-in-tariff programme, facilitating renewable energy growth.

5. A diversified low-carbon energy mix for Ethiopia

A plausible low-carbon energy mix for Ethiopia is presented in this chapter, which builds off a general overview of the energy context in Ethiopia that was covered in Chapter 3, and then delves into the associated infrastructure needs, financial implications and costs for a mix of low-carbon energy options.

5.1. Overview of Ethiopia's current energy system

Energy consumption in Ethiopia is currently, like that of many least developed countries, dominated by biomass. It is estimated that 90 per cent of all energy generation is sourced from biomass, with fossil fuels such as petroleum and coal contributing 8.5 per cent, and electricity only 1.5 per cent:

- **Residential** households are the largest consumers (91 per cent of national energy consumption) and predominantly use biomass, for cooking and heating.
- **Transport** (6.3 per cent of national energy consumption) is the principal consumer of fossil fuels, in the form of petroleum products.
- **Industry** (1.9 per cent of national energy consumption) primarily uses fossil fuels, in the form of coal and petroleum products.
- **Commercial** services (1.1 per cent of national energy consumption) are minor users of biomass and electricity.

All four of these consumer sectors are expected to grow significantly over the coming decades. Over the past 10 years, Ethiopia has experienced average GDP growth more than 10 per cent per annum, and such growth is expected to persist in the near term. With energy demand tracking this increase in productivity, the country's current overwhelming reliance on biomass and fossil fuels for its energy needs is not sustainable.

5.2. Defining an optimal energy mix

Designing, defining, and optimizing a country's energy mix is a multi-stage and multi-faceted process. Numerous scenarios that consider economic, social and environmental criteria must be compared, and the large number of inter-relationships that drive these scenarios identified with all critical linkages modelled. Moreover, the mix must flexibly cater for short- and long-term demand (and external supply) projections. This exercise presents a particularly complex undertaking in the context of a rapidly developing country such as Ethiopia, with evolving markets, major urban centres driving economic productivity, secondary cities beginning to experience rapid expansion, and rural areas undergoing fundamental socio-economic shifts.

It is difficult to break the process of defining and optimizing an energy mix into a small number of broad components because of the array of inter-linked influences and dynamics that must be considered, including specific regional, national and local contexts. However, at a basic level, a mix could be considered a combination of a technical "solution" to demand requirements and a financial "solution" that will enable sustainable implementation and maintenance of the mix. Each structure will affect the other, requiring an iterative optimization process that reaches preferred economic, social and environmental outcomes. Tying these components together is the appropriate institutional and regulatory environment, which must be developed to best enable pursuit of the chosen mix.

5.2.1. The technical solution

The optimal mix will consist of energy derived from many different sources, conveyed in a number of forms, for consumption by a large variety of end-users for diverse purposes. Key to determining an optimal mix will be an assessment of the current and future availability of energy (re)sources. Such resources may be renewable, and could exist indigenously or need to be imported (leading to a degree of energy dependence on the exporter). The assessment will include evaluation of the quality of the resources, and associated generation technologies, to provide suitable and reliable (including baseload considerations) energy in specific demand contexts.

Figure 37 below provides a simplified, illustrative example of a typical energy mix and the overall flow paths (in this case, for the USA for 2015) from generators to consumers.

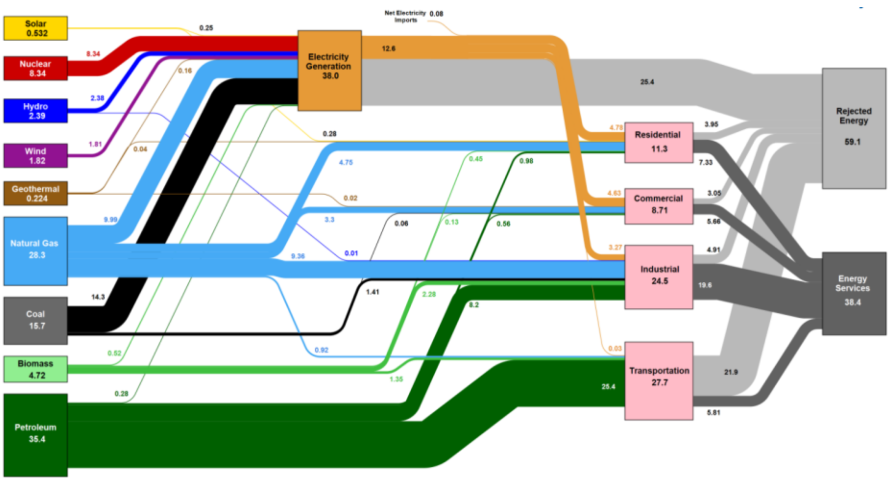

Figure 36 Illustrative Energy Mix and Flow Chart (U.S. Energy Consumption, 2015, 97.5 Quads) (Lawrence Livermore National Laboratory, 2015)

The generation technologies can be centralized or decentralized, with implications for the business and distribution models. Centralized energy tends to be traditional, large-scale production (often located near the necessary resources) and then transmitted or transported over distance to consumers. Decentralized energy, also known as distributed energy, is a modern phenomenon enabled by newer technologies, typically generated closer to the consumer, often on a smaller scale by a variety of devices; it can exist in off-grid or mini-grid scenarios (that is, it is not heavily reliant on an established transmission or distribution network).

5.2.2. The financial solution

Financial implications and commercial viability are critical determinants in the overall feasibility of the energy mix. Assessed in isolation, the best technical "solution" to the mix is unlikely to be financially sustainable; hence, an iterative process must be followed until both technical and financial scenarios are viable and optimized. Factors that can play into the financial evaluation include the following:

- Economic cost-benefit impact
- Infrastructure and resource needs (both principal and supporting, for example, infrastructure to extract and transport resources) and associated funding requirements
- End-user affordability and tariff models (including possible need for subsidization)
- Implementation and operational mechanisms (including private, public, and public-private sector participation)
- Potential for energy export (or need for import) and the cross-border implications.

5.2.3. The institutional and regulatory environment

An important part of developing an optimal energy mix is ensuring that the necessary policy and regulatory environment, and institutional structures, are established and in place to best enable and expedite the shift.

The role of the private sector, such as potential extractors, developers, producers, service providers and financiers, must be considered. It must also properly capacitate public sector role-players (taking into account national and local entities) tasked with promotion, oversight, and regulation; ensure clarity of role and mandate; and minimize bureaucratic inefficiencies and complexities. Finally, policies must be carefully structured to encourage consumer uptake of the mix, especially if new and unfamiliar technologies and sources are being promoted.

5.3. Ethiopia's optimal energy mix

It is evident that Ethiopia's current energy mix is not viable; the current sources of energy are not technically or financially adequate to support expected economic growth, and the dominance of biomass and fossil fuels in the mix is untenable. A more sustainable and optimized energy mix will be required, one that gives short- and long-term consideration to the needs of a shifting Ethiopian context.

This mix must acknowledge the eminent emergence of many of the country's secondary cities as significant future centers of economic and social growth. While an optimal energy blend must by necessity consider the country as a whole, specific geographic, geopolitical and geo-economic variations across Ethiopia will shape the optimal mix. Certain resources, technologies and distribution models may be appropriate for generation and consumption in some areas, but not others.

Ethiopia has an abundance of indigenous natural energy resources to consider, which have to date been only minimally exploited. These were highlighted and discussed in previous chapters of this monograph, and are reproduced for convenient reference here in table 12:

Table 10 Summary of Indigenous Energy Resource Potential and Current Level of Exploitation in Ethiopia

Resource	Unit	Exploitable Reserve	Exploited Percent
Hydropower	MW	45,000	< 10%
Solar	kWh/m^2/day (TWh/annum)	Average 5.5 (2.2 million) (Derbew, 2013)	< 1%
Wind: Power (Speed)	GW (m/s)	1,350 (>6.5)	< 1%
Geothermal	MW	7,000	< 1%
Wood	Million tons	1,120	50%
Agricultural waste	Million tons	15 – 20	30%
Natural gas	Billion m^3	113	0%
Coal	Million tons	> 300	0%
Oil shale	Million tons	253	0%

5.3.1. The low-carbon path

Although Ethiopia is currently a very minimal contributor to global emissions, the rapidly increasing technical and financial viability of low-carbon energy sources makes the pursuit of a generally low-carbon energy mix practical. Moreover, maintaining the current consumption trajectory will have a detrimental impact on local biodiversity, environmental conditions, and growth. An appropriate low-carbon mix will facilitate a shift from this path and can improve national and local resilience to the impact of climate change in general, including through diversity of supply. The common concern with adopting a low-carbon path is that it prevents the country in question from expanding its energy supply using fossil-based resources. In the case of Ethiopia, this is less of a concern, given the superior viability and potential of low-carbon options over non-renewable ones.

As evidenced in Table 9, Ethiopia possesses significant low-carbon, renewable resources from which it can extract energy, most of which have seen little exploitation to date. These include solar, wind and geothermal.

In line with its developmental status, Ethiopia is transitioning from an energy mix dominated by basic forms of thermal energy to one where electricity will be a major source, particularly for the residential, commercial and industrial sectors. Many low-carbon technologies concentrate on the conversion of renewable resources to electrical energy, whereas electricity generation and transmission are often more efficient than extraction and distribution of other energy forms. It is therefore logical that the country's primary focus going forward be on optimizing the low-carbon makeup of the umbrella "electrical energy" group.

5.3.2. The electrical energy mix – current and future requirements

Ethiopia is seeking to substantially increase electricity generation and coverage to accommodate and support expected economic and population growth, making it a central source of energy in the country's energy mix. Ethiopia currently consumes an estimated 65 kWh per capita per year, which is lagging that of many of its contemporaries, including Kenya (168 kWh/capita/year), Tanzania (89 kWh/capita/year), Cameroon (278 kWh/capita/year), and Mozambique (436 kWh/capita/year, possibly because of recent industrial consumption rising) (World Bank, 2015). However, current electricity demand growth is more than 25 per cent per annum, one of the highest in Africa (Lemma, 2014).

Ethiopia's electricity service coverage stood at 54 per cent in 2013/2014, and is estimated to be approximately 60 per cent currently (National Planning Commission, 2015) (the Ethiopian Electric Power Corporation estimates coverage based on the number of people within a certain proximity of distribution lines, not only those directly connected (Energypedia, n.d.)). Over the next 5 years, the country is aiming to increase coverage to 90 per cent (National Planning Commission, 2015), and over the next 20 years, EEPCo expects to increase sales from around 2,400 GWh currently to almost 18,000 GWh. Moreover, its customer base will experience a dramatic shift, as illustrated in the diagram below (Lemma, 2014). Industry will be the dominant consumer, with transport and agriculture both becoming significant users, as the country promotes industrial and agricultural growth and more efficient modes of public transport. However, the residential and commercial sectors are still expected to account for almost a third of all consumption.

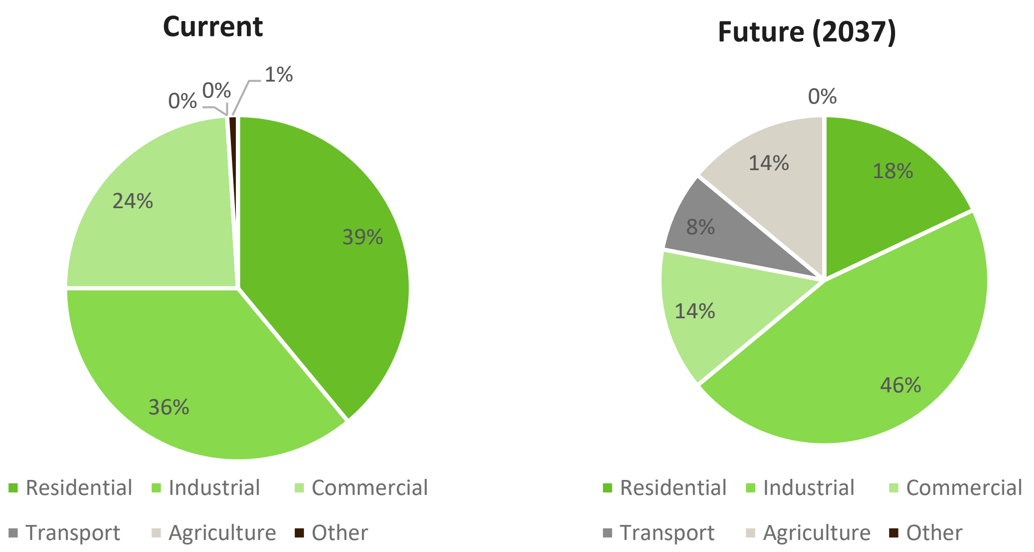

Figure 37 Shift in Ethiopia's Electrical Energy Customer Base and Consumption Share over Next 20 Years

Ethiopia's current generation capacity of 2,400 MW is predominantly sourced from hydropower, which as a resource is, and will likely remain, the country's energy backbone for the foreseeable future given the country's hydro resources. The current mix of Ethiopia's generation capacity is highlighted in Figure 38 below (MoWIE, 2015).

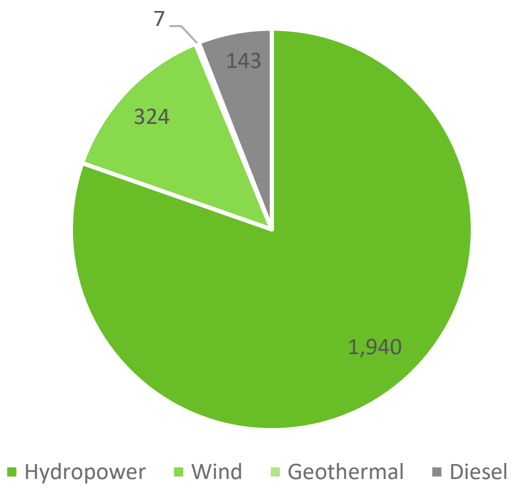

Figure 38 Breakdown of Ethiopia's Current Electrical Generation Capacity (in MW)

To meet the expected short -and longer-term growth demand, and accomplish its low-carbon electricity generation and distribution expansion objectives, Ethiopia will need to invest in significant infrastructure, systems and capacity over the coming years to expand and diversify its current generation capacity. Aside from hydropower, renewable sources with high potential for development include geothermal, wind and solar. The country should also explore the viability of its natural gas reserves as an electricity-generating resource. Although not renewable, natural gas and closed-cycle gas turbines (CCGT) are cleaner burning and more efficient than their diesel counterparts.

This resource and generation diversity will have benefits such as providing consistent baseload capacity. In isolation, variable resources such as wind and solar would not be able to guarantee consistent supply without additional (expensive and complex) storage infrastructure. In addition, diversity will guard against the negative impact of climate change and improve the country's supply resilience. Water resources, and hence the reliability of hydropower, are at threat from climate change. In contrast, geothermal energy, by virtue of the natural resource it harnesses, is extremely climate change-resilient.

5.3.3. The non-electrical energy mix

Although electricity will play a dominant role in Ethiopia's low-carbon energy mix, several other sources and forms of energy will service a market.

In particular, the country's transport sector will likely remain a major and growing consumer of fossil fuels, particularly petroleum products. However, the development and use of sustainable bio-fuels can be a viable component of the transport energy mix. Promotion of niche technologies with the potential for growth in the future, such as electric vehicles, should also be considered. Ethiopia has already implemented Phase 1 of its Light Rail Service, which operates electric-powered rolling stock; the majority of the 8 per cent electricity demand share projected by the EEP for transport in 2037 is earmarked for rail.

Electrification roll-out and mass adoption across Ethiopia into smaller cities and rural areas will also take time, even in basic distributed form. In the interim, energy derived from processed agricultural waste and sustainably cultivated biomass can substitute for unsustainable forms, particularly in residential households for cooking, heating and lighting.

Petroleum products such as kerosene and LPG are always likely to find a niche use in the residential and commercial sectors. Fossil fuels such as coal and natural gas will also be in demand in the industrial sector for various energy applications where electricity is not technically or financially viable.

5.4. Infrastructure needs and financial implications for a low-carbon energy mix

According to Ethiopia's GTP II, it is seeking by 2020 to almost triple the number of customers accessing a formal electricity provision service. In doing so, it hopes to (National Planning Commission, 2015):

- Increase generation capacity from around 2,400 MW to over 17,000 MW
- Construct an additional 8,900 km of high-voltage transmission lines
- Double the line length of the distribution network to more than 260,000 km (Lemma, 2014)
- Promote an annual per-capita electricity consumption increase of close to 1,500 per cent.

By 2037, the Ethiopian Electric Power Corporation plans to increase generation capacity to more than 32,000 MW, or an average capacity installation rate of 1,500 MW per year from

2017. Several projects are already underway, in various stages of preparation and development, in the hydropower, geothermal, solar and wind sectors. However, substantial additional investment and development is required.

The graph below is derived from Ethiopia's *Power System Expansion Plan 2014*. Although not necessarily representative of the optimal low-carbon energy mix path Ethiopia should pursue, it does provide an indication of the kind of technology mix, and therefore infrastructure and financing, that would be required to meet demand requirements.

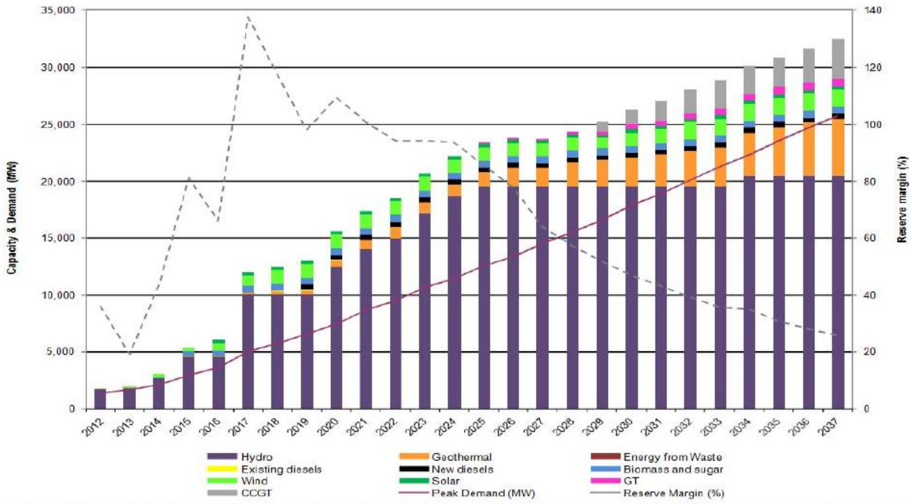

Figure 39 Electricity Generation Capacity Development to 2037 (MoWIE, 2015)

Hydropower continues to dominate the mix; however, investment in geothermal, wind and natural gas capacity is noteworthy. Solar energy is not significantly represented in this particular projection, which is likely not to be the case in reality. Solar technology, especially solar PV lends itself very well to distributed (non-centralized) and off-grid development, which is possibly not reflected in the chart above, given its context.

5.4.1. Infrastructure costs

A part of Table 10 below provides indicative infrastructure development costs for the five broad technologies that constitute the majority of the above-postulated energy mix (IRENA, 2014) (U.S.S. Energy Information Adminstration, 2013) (MoWIE, 2015). The broad varieties and contexts these technologies exist in make the estimation of a consolidated unit installation cost difficult. Hence, a typical range and weighted average is provided, based on the costs of previous projects. Most of the data in Table 11 were derived from the International Renewable Energy Agency, which curates a detailed global project database and annually reports on the trends in renewable energy costs. Where possible, only Africa-specific costs have been tabulated, to take into account better the fledgling nature of many of these technologies in an African context.

Table 11 Indicative Energy Infrastructure Unit Install Costs and Estimated Total Cost for Hypothetical Low-Carbon Mix

Resource	Installed Costs (US$/kW)			Capacity to be Developed (kW)	Total Cost of Development (US$)
	Low	Average	High		
Hydropower					
Small	3,000	3,800	5,500	0	0
Large	500	1,500	6,800	16,000,000	24.1 billion
Solar					
PV – Utility	1,800	3,100	4,900	500,000	1.55 billion
PV - Residential		2,100/ 4,000		500,000	2 billion
CSP	6,000		12,000	1,000,000	8 billion
Wind	1,400	2,200	3,000	1,700,000	15.1 billion
Geothermal		4,000		5,000,000	20.0 billion
Natural gas					
CCGT		1,000		4,000,000	4.0 billion
CCGT with carbon capture		2,100		0	0
TOTAL					**74.7 billion**

Notes

- Costs applicable to utility scale, unless otherwise noted.
- Where possible, data are reflective of costs applicable to Ethiopia/Africa.
- Solar CSP incorporates all technologies, and includes average 5 hours of storage capacity.
- PV residential average is a global figure, likely to be upwards of $4,000/kW in Africa ($4,000/kW used for total cost calculations).

The right-hand side of Table 11 offers a high-level estimate of the amount of capacity to be installed for each of these technologies to match approximately the proposed year 2037 mix. A conservative adjustment has been made to incorporate a suggested 2,000 MW of solar energy in lieu of a similar amount for hydropower, to harness Ethiopia’s abundant solar resources and better represent a likely decentralized approach in some areas of the country. Small-scale hydropower, and combined-cycle gas turbines (CCGTs) with carbon capture and sequestration, have been omitted for the sake of simplification. Based on these capacity estimates and the weighted average installation costs for each technology, a total cost of development in today’s terms can be projected.

This total generation infrastructure cost, summing to approximately $75 billion, is a basic indication of the capital funding needs for a hypothetical low-carbon energy mix and development strategy over the next 20 years (noting that some of this capacity development is already underway, and that installed costs are unlikely to remain static in real terms over the 20-year period). Additional funding would be required to develop the infrastructure for niche energy sources not considered above, such as waste-to-energy. These infrastructure costs (and infrastructure life-spans for each of the technologies, which would determine replacement cycles) would need to be considered when optimizing the energy mix between conventional and low-carbon sources, and among types of low-carbon sources.

This total does not include the required funding for development of transmission and distribution infrastructure and other supporting systems in a country like Ethiopia, where existing development is low. These costs are likely to be substantial if the focus is on centralized generation; Ethiopia is a large country with a relatively low population density. The spatial distances between economic centers are large, and there is a wide dispersion of people in the rural areas. Hence decentralized energy options should play a significant role in the optimal energy mix; low-carbon renewable technologies such as solar PV, solar CSP, micro-hydropower, and micro-wind are well suited to off-grid and micro-grid applications. Natural gas close-cycle gas turbines are also a convenient “drop-in” energy generator, although the logistical challenge then shifts to reliable procurement of natural gas feedstock.

5.4.2. Operational costs and affordability considerations

The infrastructure development costs for energy capacity installation and support infrastructure are only part of the financial consideration required in designing and optimizing the energy mix. Over an installation’s lifespan, it will incur operational and maintenance (O&M) costs associated with generating and distributing energy for the consumer.

O&M costs can broadly be split into fixed and variable costs. The latter typically refers to the cost of the raw resource feedstock. Many renewable and low-carbon technologies, such as hydropower, solar, wind and geothermal, do not incur any variable costs, as the resource is freely available. Gas turbine generators, on the other hand, must be run off natural gas. The variable cost of that gas will reflect the costs of acquisition, influenced by exploration, extraction, storage and transport.

The left side of the table below provides a high-level indication of the fixed and variable operational and maintenance costs (U.S. Energy Information Adminstration, 2013) associated with the technologies previously covered, extracted from U.S. Energy Information Agency calculations (given the lack of African data). Even more so than infrastructure installation costs, it is challenging (and perhaps even misleading) to distill O&M costs down to a single figure per technology; each generation plant will have its own unique operational context that will influence its figures.

Nevertheless, generic estimations are a starting point to costs that must be factored into the overall energy mix feasibility calculations, in conjunction with the installation costs. Large-scale hydropower plants, for example, typically have significant up-front capital requirements given their overall size, but ongoing operational and maintenance costs are low, effectively "front-loading" the life-time financial investment. CCGTs, on the other hand, have a highly competitive installation cost, but more substantial operational and maintenance costs over a life-span that is typically shorter, and therefore requires replacement sooner than hydroelectric infrastructure. These funding considerations will affect the overall economic feasibility of the energy mix.

Table 12 Indicative Energy Technology Operational and Maintenance Costs, and Levelized Cost of Electricity

Resource	**Operational & Maintenance Costs**		**Avg. Levelized Cost of Electricity (US$/kWh)**
	Fixed (US$/kW-yr)	Variable (US$/MWh)	
Hydropower			
Small	40.00	0	0.050
Large	14.13	0	0.040
Solar			
PV – Utility	24.69	0	0.195
PV - Residential	27.75	0	0.350
CSP	67.26		0.350
Wind	39.55	0	0.095
Geothermal	100.00	0	0.090
Natural Gas			
CCGT	13.17	3.60	0.070
CCGT with carbon capture	31.79	6.78	-

Table 12 also provides some very basic estimates of the average LCOE for the technologies in question (IRENA, 2014). The LCOE attempts to represent, in a single metric, the comparative cost of a unit of electrical energy generated by that technology, considering all lifetime costs incurred (including financing costs such as interest on debt).

LCOE figures are derived from already generalized infrastructure and operational costs, because of the number of assumptions that go into the calculation (including financing costs), as well as the differences in costs among projects and geographic regions; it can never be more than a rudimentary estimation. However, taking its assumptions and limitations into account, it does have value as a comparative tool in highlighting relative commercial competitiveness among technologies. Moreover, it provides a high-level suggestion of affordability, or lack thereof. In the simplest scenario, it indicates the minimum amount the market must pay for each unit of energy consumed for the technology to be commercially viable.

The current average domestic tariff in Ethiopia is ETB 0.60/kWh, which equates to around $0.03/kWh. By comparing this figure to the LCOE figures in Table 12, it can be inferred that it is unlikely the entire costs of any of the technologies will be fully recovered from the consumer at current tariff levels. Affordability to the consumer, especially in a low-income country like Ethiopia, and the ability of the government to partly subsidize the cost of energy provision, become important factors in the determination of the energy mix. Some low-carbon sources tend to currently be slightly more expensive than conventional sources of energy (although this is rapidly changing as low-carbon adoption becomes more widespread globally), and hence there may be an explicit cost premium associated with following a diversified low-carbon path. However, long-term benefits may outweigh this premium; this is why vigorous cost-benefit analyses become important in optimizing the energy mix.

Transmission and distribution costs must also be added to the generation of LCOEs above, particularly for centralized generation. In Ethiopia, the LCOE is approximately $0.007/kWh, and for distribution is $0.014/kWh (Ministry of Water and Energy, 2012).

5.4.3. The role of the private sector

The Ethiopian power sector is led by public sector entities, headed up by the Ministry of Water, Irrigation, and Energy. However, an investment code was formulated in 1998 to promote private sector participation in the power generation business. The foreign private sector can currently participate in hydropower generation without capacity limit, and there is some small involvement in current geothermal, solar and wind developments. The private sector can also partake in electrical equipment manufacturing and invest in off-grid rural electrification ventures (Derbew, 2013).

However, a significant expansion of Ethiopia's policy and willingness to attract foreign private sector expertise and capital is required if it is to implement successfully a low-carbon energy mix pathway. Beyond policy and will, the country will need to assure it has the structures and capacity in place to accommodate private sector participation, at both the micro and macro scales, and including PPPs. Local public and private sector capacity, both technical and financial, is limited, and therefore will not be able to meet the required demands of developing and operating additional capacity across multiple new technologies. A partial and structured deregulation of public sector utility control over energy provision can also encourage innovation at a smaller and decentralized scale, particularly among local entrepreneurs and institutions. Countries such as Kenya and South Africa have highlighted and reaped the expedited benefits of encouraging structured private sector participation in the energy sector.

From a commercial viewpoint, IPPs and similar will only have an appetite to invest in the Ethiopian energy sector if they can recover their costs and earn a profit on their investment. As it stands, this may be challenging without government subsidization, with Ethiopia having some of the lowest electricity tariffs in the world. Government will need to carefully consider the impact of raising tariffs closer to cost-recovery levels; higher prices may detrimentally affect the drive to get people to adopt electricity over other forms of energy. In addition, many Ethiopians may not be able to afford the new tariffs.

5.5. Trade implications of a low-carbon energy mix

Ethiopia's diverse abundance of high-quality renewable energy resources means that, in following a low-carbon energy mix path, it will also largely be ensuring its long-term energy self-sufficiency and independence. As a key member of the Eastern African Power Pool (EAPP), the country will almost certainly maintain its position as a net exporter of electricity, with an estimated 44 per cent surplus over the next 20 years.

The EAPP is also making a concerted push towards renewable and low-carbon energy options, with grid-connected large-scale wind, solar, geothermal and hydropower systems a priority. This aligns with the likely make-up of an optimal low-carbon energy mix for Ethiopia; the country will be in a strong position to sell energy to neighbouring countries and use the revenue to party cover costs associated with meeting its own energy needs.

Transmission lines are already in place between Ethiopia and Djibouti, and Ethiopia and Sudan, with combined capacity of close to 150 MW. Two Kenyan border towns are also connected, while a 500-kV high-voltage line is currently under construction, and Memorandums of Understanding are in place with Tanzania, Rwanda, South Sudan, Yemen, and a second line to Djibouti (Lemma, 2014).

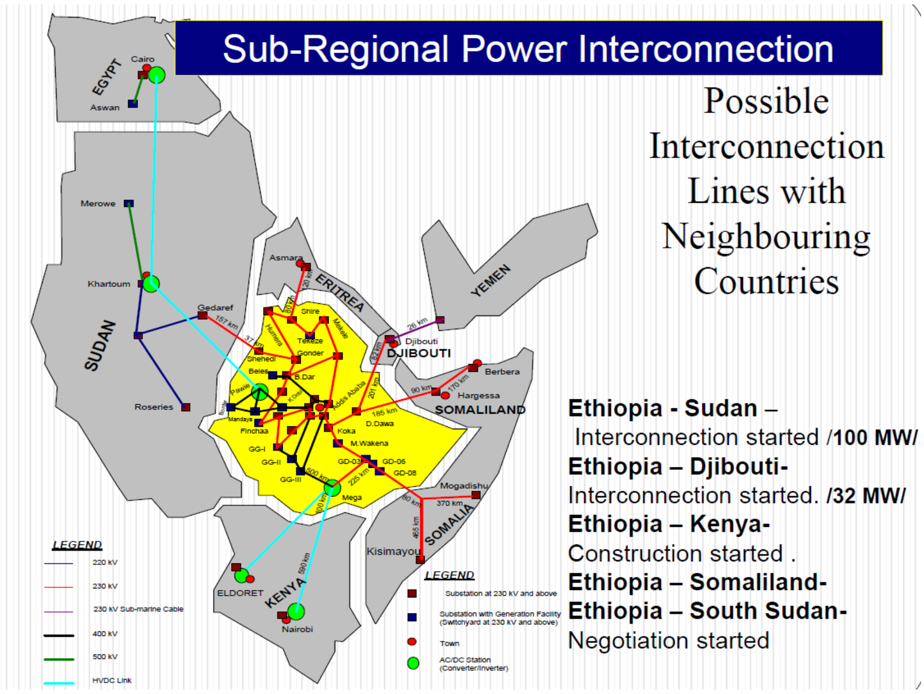

Figure 40 Planned Interconnecting Electricity Transmission Lines between Ethiopia and Neighbouring Countries (Derbew, 2013)

Ethiopia currently imports all its petroleum products, and this will likely continue in the future, given expected demand from growth in motor vehicle and air traffic. The country is beginning to develop low-carbon public transport options; Phase 1 of the electrically driven Light Rail system in Addis Ababa is operating, with several more phases and similar projects planned nationally. Locally produced bio-fuel may also reduce the dependence on imported fuels. Natural gas derivatives can also replace oil petroleum products in some instances, and although not renewable or low carbon, it is a significantly cleaner-burning fuel.

5.6. Conclusion

Given the insufficient data and technical information available for Ethiopia's energy sector, and in particular for its renewable energy sources, it is not currently feasible to define a precise power mix for 2035. To be able to do so in a credible manner, a host of studies needs to take place, such as resource mapping, LCOE studies, and so on. However, the research reflected in this current report suggests that such an energy mix, with greater diversity of low-carbon sources beyond merely hydropower, is technically feasible. Transitioning towards a more diverse mix of this nature comes with several costs, including sizeable infrastructure costs (estimated at $75 billion at the least). However, this would lead to a more sustainable and energy-secure future for Ethiopia. The burden of financing this transition need not fall on the government alone; the private sector can be drawn in to spur such development, and private investment as well as efficiency leveraged to fund such renewable energy growth in Ethiopia, just as it has in several other countries. In the future, Ethiopia may also be able to recover some of its costs by exporting power to its neighbours through the EAPP.

6. City Case Studies – Diré Dawa and Mekelle

Case studies of two of Ethiopia's secondary cities offer insights into current energy patterns and the need for greater access to reliable, low-carbon, sustainable energy sources.

6.1. Diré Dawa

Diré Dawa is a land-locked city and the administrative centre of the Shinile region in eastern Ethiopia. The population was estimated to be 341,834 in 2007 and is projected to increase to 453,000 in 2016, with an urban population of 285,000 according to the CSA (CSA, 2013). This population size results in Diré Dawa being the second most populous city in Ethiopia (CSA, 2013), and the percentage of the population residing in urban areas of Diré Dawa is estimated at approximately 62 per cent, three times higher than the national urbanization statistics. From an institutional perspective, Diré Dawa is the only city, apart from Addis Ababa, that has been granted Charter City status by the national government. Such a status accords the city semi-autonomy regarding land- use and institutional decision making, compared to other secondary cities. Despite this distinct status, the city faces a host of challenges. It is estimated that one-third of the urban population has no access to water. Three-quarters of marginalized groups have reported an acute lack of ability to satisfy food and clothing needs. There are at least 15,000 city dwellers living in high flood-risk areas, and an additional 160,000 living in impoverished, unserved areas or in sub-standard housing (UN Habitat, 2008).

The city is home to a diverse set of ethnic groups, and it is a major distribution point for goods and produce being transported from the port of Djibouti, the only seaport open to Ethiopia. The city's economy is characterized by heavy industry, textiles, cement, commercial trade and agriculture. Additionally, Diré Dawa has Ethiopia's only international airport outside of Addis Ababa (ECA, 2014).

Diré Dawa, like most secondary cities in Ethiopia, faces enormous development challenges and does not exhibit the institutional capacity to attract investment or to support business development or the creation of employment opportunities through economic activities (Roberts, 2014).

6.1.1. Climatic profile and climate change trends

Diré Dawa's climate is a local steppe climate, with minimal rainfall throughout the year. The climate here is classified as BSh (that is, a hot, arid or semi-arid steppe climate) by the Köppen-

Geiger system. The average annual temperature is 24.6 °C in Diré Dawa, and the average annual rainfall is 637 mm. As illustrated in the figure below, precipitation is lowest in December, with an average of 6 mm; most of the precipitation falls in August, averaging 125 mm. In addition, at an average temperature of 27.7 °C, June is the hottest month of the year, and January is the coldest month, with temperatures averaging 21.2 °C. Between the driest and wettest months, the difference in precipitation is 119 mm, and throughout the year temperatures vary by 6.5 °C (Climate-Data.Org, n.d.).

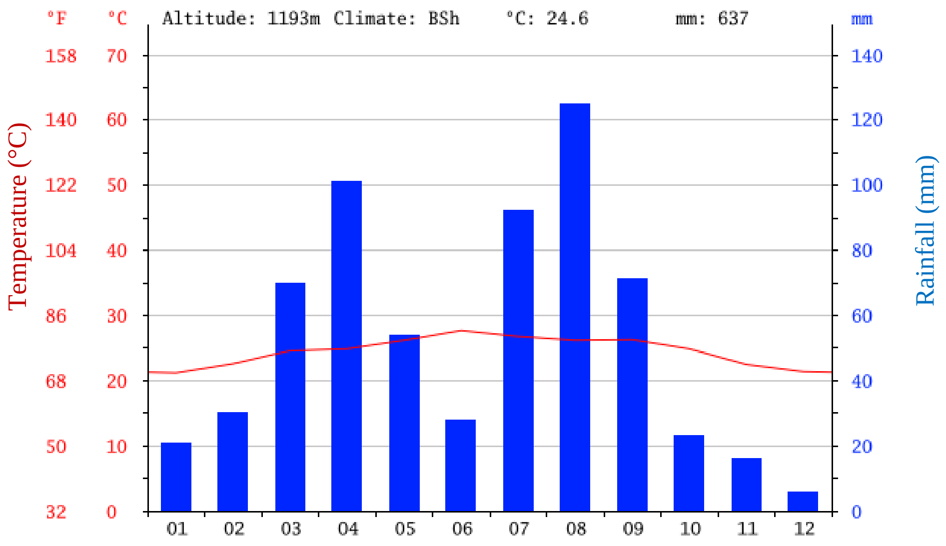

Figure 41 Monthly Temperature and Rainfall Data for Diré Dawa (Climate-Data.Org, n.d.)

Analysis of the average annual rainfall trends in the past three decades in Diré Dawa suggests a more or less constant trend. However, the last 10-year trend indicates a decrease in rainfall amount. Contrary to this (albeit statistically insignificant), is a trend analysis over the last 30 years of specific periods of rainfall: March-April and June–September. This 30-year period-specific trend demonstrates an increase in rainfall over the period. These analyses underscore that Ethiopia experiences high rainfall variability, especially over a long period. Such rainfall variability contributes to drought conditions in many parts of Diré Dawa.

In addition, like other regions of Ethiopia, the issue of floods continues to be of growing concern in Diré Dawa, especially to people residing in lowlands, along or near the flood courses, and as villages located at the foot of hills and mountains. Flood disasters have been occurring more frequently and have been taking a toll on Diré Dawa in terms of the costs in lives, livelihoods and environmental resources. Because of global climate change and local environmental pressures, the occurrence and frequency of flood hazards and the magnitude of destruction from floods are increasing over time (DDAEPA, 2011). Diré Dawa witnessed dangerous flooding as recently as May 2016, during the course of this research.

An assessment made by NMA (2007) reported that, in the case of IPCC mid-range (A1B) emission scenario, the mean annual temperature in Diré Dawa will increase up to 1 °C by 2030, 1.8 °C by 2050 and 3 °C by 2080 compared to the 1961-1990 normal. On the other hand, mean annual rainfall is likely to increase in Diré Dawa by 3.4 per cent by 2030, 6.4 per cent by 2050 and 10.5 per cent by 2080 compared to the 1961-1990 normal (DDAEPA, 2011). A study conducted in the Awash Basin, where Diré Dawa is located, indicates that there is significant temporal and spatial variability of rainfall over the basin. No clear regional rainfall pattern can be discerned, as there are both decreasing and increasing tendencies of rainfall in different reaches of the basin. Moreover, the increase of rainfall has concentrated in the rainy months of June to September when irrigation is limited. As indicated in NAPA, trend analysis of annual rainfall shows that there was no trend over the last 55 years. However, NAPA has projected the increase of normal annual rainfall by 3.4 per cent and 6.4 per cent in 2030 and 2050, respectively, and these figures, together with temperature increase, have been used in developing climate change scenarios (Tiruneh, 2013).

Current climate variability already poses a significant challenge to Ethiopia in general and Diré Dawa in particular, by affecting food security, water and energy supply, poverty reduction and sustainable development efforts, as well as by causing natural resource degradation and natural disasters. Prolonged droughts time and again affected the rural part of Diré Dawa. For example, the 2004 and 2005 droughts (which posed food shortage to the rural population equal to 85 per cent of the current population figure) are still fresh in the memories of many people. Recurrent floods in the past caused substantial human life and property loss in many parts of the urban kebele (the August 2006 flood claimed 256 lives, displaced 2,500 families, and caused direct damage estimated at ETB 100 million and indirect damage of similar magnitude). These challenges are likely to be exacerbated by anthropogenic climate change (DDAEPA, 2011).

6.1.2. Energy profile and energy trends

Cities in Ethiopia account for only 18 per cent of the population but for nearly all the industrial output, and most of the motorized transport activity and services. Most of the energy consumed in industry, transport and services is therefore consumed in cities like Diré Dawa.

All secondary cities are served by the national power grid, and it is estimated that more than 95 per cent of households in such cities are connected to the grid. These cities, including Diré Dawa, also have relatively good access to liquid fossil fuels (for transport and for industry). However, for household cooking purposes, most households in Diré Dawa still use solid biomass fuels, chiefly wood and charcoal (the percentage of urban residents using solid fuels for cooking in 2011 was estimated as an average of 74 per cent for all major cities, and 80 per cent for Diré Dawa) (CSA, 2012).

Figure 42 - Fuelwood Inflow into Diré Dawa (Diré Dawa Environmental Protection Authority, 2013)

One of the potential reasons for continued reliance on solid fuels for household purposes in Diré Dawa is that electricity and petroleum fuel supplies are not particularly reliable, given frequent power blackouts and fuel supply constraints (this is true of other cities as well). In 2011, for example, more than three-quarters of households in Diré Dawa suffered power blackouts two or more times per week (each lasting between 4 and 24 hours).

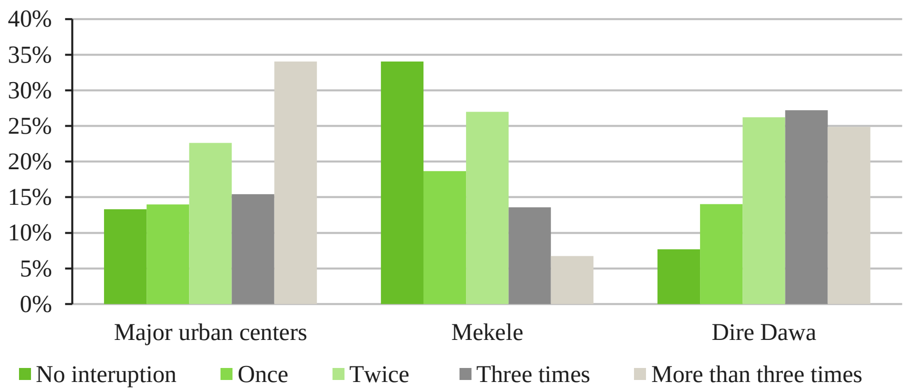

Figure 43 - Weekly Frequency of Power Interruption in Major Cities, 2011 (CSA, 2012)

6.2. Mekelle

Mekelle is the capital city of Tigray National Regional State, with a total area of about 200 km^2 and total population of 215,914 in 2007 (CSA, 2007). By 2016, this population is expected to reach an estimated 340,859 (CSA, 2013). It was founded in the 14th century on the western side of the Endayesus mountain ranges. The local economy includes agro-processing and manufacturing, textile and leather sectors, and meta-related activities.

From an urbanization perspective, the city of Mekelle is experiencing high population growth and haphazard settlement expansion, resulting in urban sprawl (Gebregziabher, et al., 2014). City authorities have responded with periodic expropriation of adjacent rural land to extend the urban limits and, effectively, provide more land for development. Between 2005 and 2008, thousands of farmer households were expropriated from their farms because of the rapid expansion of the city. This form of urban expansion by the expropriation of rural land results in an increasing urban land footprint that is a key contributor to the significant urban growth rates reported for Ethiopia as a whole. Between 1994 and 2005, Mekelle city's land coverage increased threefold from 24 km^2 to 74 km^2 because of such expansion (Gebregziabher, et al., 2014).

6.2.1. Climate profile and climate change trends

Similar to Diré Dawa, Mekelle's climate is a local steppe climate, with little rainfall throughout the year. The climate here is also classified as BSh (that is, a hot, arid or semi-arid steppe climate) by the Köppen-Geiger system. The average annual temperature in Mekelle is 19.1 °C, and the average annual rainfall is 581 mm. As illustrated in the figure below, June is the warmest month of the year with an average temperature of 21.3 °C, and the lowest average temperatures in the year occur in December, when it is around 16.5 °C. The driest month is January, with 5 mm of rain, and the greatest amount of precipitation occurs in August, with an average of 202 mm; thus there is a difference of 197 mm of precipitation between the driest and wettest months. The variation in temperatures throughout the year is 4.8 °C (Climate-Data.Org, n.d.).

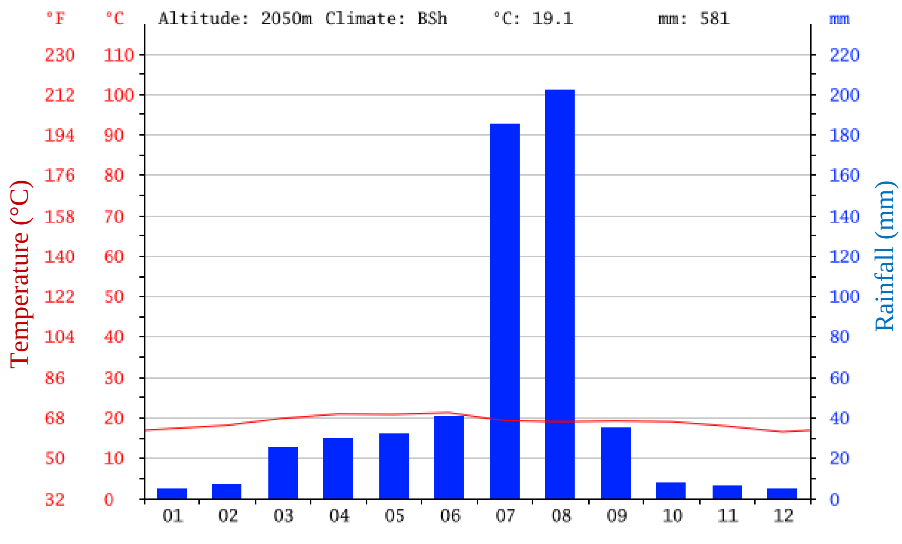

Figure 44: Monthly Temperature and Rainfall Data for Mekelle (Climate-Data.Org, n.d.)

Mekelle is in the Geba Basin, a sub-basin of the Tekeze basin (as shown in Figure 45). According to a study conducted by Goitom et al. (2012), the climate change predictions for the Geba Basin indicate that overall precipitation will decrease and PET will increase, especially in the Kiremt season. This will lead to a decrease in river flow by as much as 50 per cent for the A2 climate scenario and by 43 per cent for the B2 climate scenario. There may be less difference in precipitation or PET in the Bega season. The reduction in river flow is more pronounced in the Kiremt season (Goitom et al., 2012).

It is very likely this will lead to increased water stress in the forthcoming decades. Therefore, it can be surmised that the climate change impact may be significant. In fact, the northern highlands of Ethiopia are likely to become even more susceptible to severe drought conditions than what is presently experienced. As Kiremt is the only cropping season in the northern part of Ethiopia, these results imply a very severe impact of climate change on rain-fed agriculture and natural vegetation (Goitom et al., 2012).

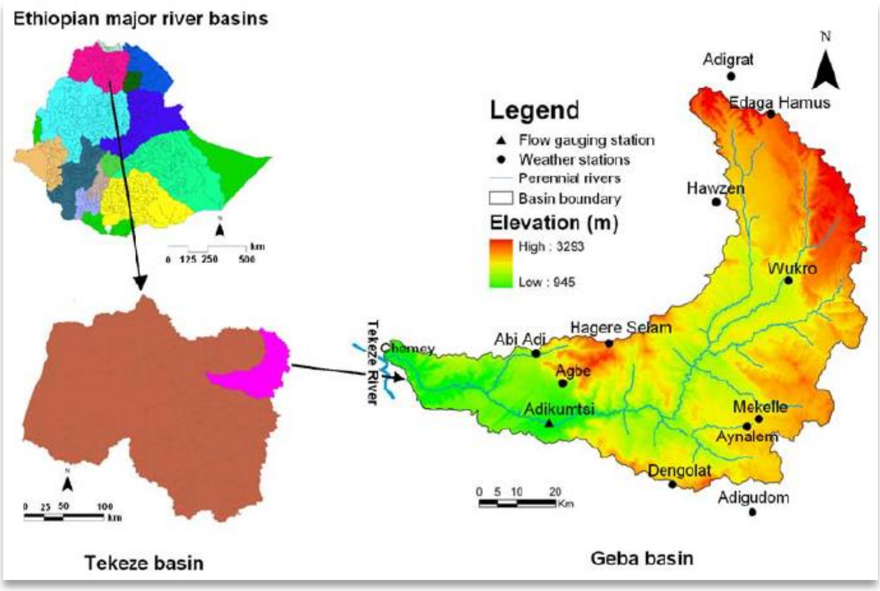

Figure 45 Map of the Geba Basin with topography (Goitom et al., 2012)

6.2.2. Energy profile and energy trends

Electricity: Data obtained from Mekelle, North district EEU office, state that the number of connected customers by customer category in Mekelle City in 2014 was 30,462 households, 7,453 general consumers such commercial establishments and services, and 178 industries. The population of Mekelle City in 2014 was estimated at 286,624, which amounts to 57,325 households (EEU, 2014). Hence, the percentage of direct meter-connected households in

Mekelle City in 2014 was about 53 per cent. (Shared meter connection is a common practice in Ethiopia and is still a highly prevalent method for most households to connect to grid electricity. National-level data for electricity connection show that there were 1.4 shared meter connections for every direct-metered connected household (CSA, 2012). However, because of frequent blackouts, reliance on electricity has not strengthened as expected; in 2011, half of households in Mekelle suffered recurrent blackouts.

Cooking fuels: Major cooking fuels for households in Mekelle are charcoal and fuelwood, with approximately 68 per cent of households relying on them for cooking. Because of scarce biomass in the semi-arid region, the price of biomass cooking fuels in Mekelle is one of the highest in the country. A recent study shows that the average prices of charcoal and firewood were 5.95 ETB/kg and 2.60 ETB/kg (Megen Power, 2014). The same study also shows that price of charcoal grew by 5-fold in the last 10 years.

As part of a strategy to improve household energy options in Mekelle and reduce impacts on the environment, the Regional Energy and Mines Agency (REMA) promotes widespread use of electricity for cooking and baking. The agency also promotes efficient utilization of biomass fuels through distribution of improved cook stoves. REMA also works with households to promote urban agriculture, particularly in the suburbs of Mekelle, and to adopt biogas digesters as a source of cooking energy and light. REMA also promotes solar technologies in parts of Mekelle where the grid is not accessible.

Low-carbon technologies that are being promoted for households in Mekelle and other similar cities are cook stoves (electric cook stoves, improved biomass cook stoves for charcoal and firewood, domestic biogas technologies, and solar lanterns and home systems). In Mekelle, the electricity demand growth from industries is extremely high. The existing sub-station can no longer handle the requirement, exacerbated by the high electricity demand from Mosobo Cement Factory, which consumes more than the total of all the other sectors. Such capacity limitation has become a hurdle for the promotion of electricity for cooking.

6.3. Observations from the case study cities

Both Diré Dawa and Mekelle demonstrate a need for stronger, more reliable energy sources to supply greater energy services. They both also demonstrate potential for increased reliance on such sources, be it through rooftop solar power, or municipal waste-to-energy power, or other distributed generation, to supplement electricity from the national grid.

Indeed, it should be noted that both Diré Dawa and Mekelle are connected to a centralized grid. According to official statistics, most households in both cities have access to grid-based power. When the research team visited both cities, it also observed that most neighbourhoods had transmission lines bringing power to virtually all areas of the city. Despite this, reliance on electricity for cooking is very low, and there is a high degree of reluctance to shift to electric cooking. This reluctance is surprising given that traditional fuels like charcoal and fuelwood are getting increasingly expensive, and electricity in Ethiopia is highly subsidized and therefore reasonably priced.

The research team's investigations in the two cities (including through two workshops with diverse stakeholders, including faculties from local universities) revealed that the main reasons for continued reliance on traditional fuel for cooking are three-fold:

1. Grid-based power is unreliable and intermittent, in particular because of poor-quality infrastructure that has not been well maintained.
2. Most households are not directly connected to the meter, and instead purchase power through secondary channels; that is, they pay a neighbour with a metered connection to draw power off his or her lines, and they are often charged higher rates than the original tariff, making electricity more expensive than it might be if they were connected directly to the grid.
3. Electric cooking appliances available in Ethiopia have not been demonstrably good substitutes for traditional cook stoves to cook injera, Ethiopia's staple food (a type of bread). Given how important injera is to the local diet and the cultural attachment to well-cooked injera, electric cook stoves that do not replicate the same thermal energy used to cook injera are not an attractive option for many households.

With the population of such secondary cities as Diré Dawa and Mekelle expected to double in the next 20 years, and per capita consumption of energy expected to rise markedly, it is important that households, by far the biggest consumers of energy in these cities, be provided adequate, reliable, affordable and effective alternatives to carbon-intensive traditional fuels. Similarly, more reliable and uninterrupted power at affordable rates is important for households to start investing more in electric appliances and relying more on such appliances to improve overall productivity. Critically, such a shift would also have public health and gender equity benefits.

Besides improvements in the existing grid system (including upgrading infrastructure), another approach to greater energy security in cities like Diré Dawa and Mekelle would be to encourage distributed energy generation to serve local needs. Cities are well suited to options like rooftop solar water heaters, or biogas digesters for a group of households, or even a municipal waste-to-energy plant. Local authorities should be empowered to explore such options.

7. Issues for Consideration

This chapter makes note of a range of issues that have a bearing on Ethiopia's ability to increase the diversity of low-carbon energy sources into its energy mix, particularly to enable inclusive growth in growing secondary cities. These factors are enumerated and briefly discussed here not by way of conclusions, but rather as an effort to flag, for those conducting further research, the complex mix of elements that must continue to be interrogated while exploring climate-resilient clean energy solutions in Ethiopia.

The chapter then moves on to underscore the insights derived from Chapter 6. Primarily, the central finding of the project as a whole, which is that Ethiopia's current power sector market structure and decision-making regime need to undergo change if secondary cities are to have some agency in determining or even influencing their energy mix. Some key actions at the national and sub-national levels are identified as necessary to facilitate this transformation. Finally, the chapter closes with an illustrative (not exhaustive) list of necessary future research that is needed to better inform policy makers and implementing agents as they try to operationalize the growth and integration of more low-carbon energy sources in Ethiopia.

At the outset of the project, it had appeared that an investigation of low-carbon, environmentally sustainable, alternative energy sources in Ethiopia was premised on two reasons:

1. Inadequate access to energy services in Ethiopia, including in rapidly growing cities with rising energy needs
2. The vulnerability of Ethiopia's energy sector (hydropower and biomass energy) to the impacts of future climate change.

However, research over the course of the project has underscored more significant reasons to drive a shift in Ethiopia's energy sector:

- Overwhelming reliance on biomass-based energy by households for cooking purposes, which has public health and environmental consequences (including economic externalities that are not captured in conventional energy-pricing and cost-benefit assessments). While this reliance on biomass is unsurprising in rural areas, what is striking is that, even in urban areas (including secondary cities like Diré Dawa and Mekelle), households still prefer to use charcoal, firewood and other biomass for cooking over alternatives like electric stoves. Altogether, over 90 per cent of Ethiopia's total energy use is still biomass-based.

- This entrenched use of carbon-based energy in households is matched by the use of carbon-based energy in industrial entities. Coal is a common fuel for thermal energy in industrial processes, such as in cement factories. Cement appears to be a growing industry in Ethiopia (tied in part to the country's booming construction sector), and plans to establish several industrial parks around secondary cities suggest industrial fossil fuel use will only continue to rise unless viable alternatives are actively encouraged.

Carbon-intensive sources of energy bring with them significant negative environmental and public health impacts. Beyond an imperative to transition towards a clean energy economy (which, despite Ethiopia's own policy goals and green economy aspirations, is less of a driving force in Ethiopia and similar countries with negligible GHG emissions), the real motivation to opt for cleaner, low-carbon energy choices (for both electricity and cooking fuel) is to ensure access to safe, modern, reliable energy services in Ethiopian cities without the damaging consequences on people and the environment. Scaling up cleaner energy can help ensure that communities in urban areas enjoy a full suite of energy services and leverage these to increase productive activity, which will accelerate economic growth.

In this context, any consideration of alternative energy choices must consider the following factors:

Institutional Arrangements: In Ethiopia, all energy decision making is the domain of the central government. In Ethiopia's vertically integrated single buyer model, the state owns and manages generation, sale, distribution and transmission. Energy-generation facilities and infrastructure are commissioned (and sited) by the central government, while regional and local governments do not currently have influence over local or distributed generation options. For municipalities and city governments to drive initiatives to make their own energy profile more climate-resilient and environmentally and socially responsible (such as rooftop solar water heating installations, municipal waste-to-energy biogas plants, or a micro-grid running on solar or wind power) would require a shift in institutional and regulatory frameworks.

Currently, EEP is the single buyer of power from any generation facility. In recent years, the market has opened up to some degree to grant generation licenses to IPPs on a case-by-case basis. EEP negotiates power purchase agreements with IPPs in the absence of a standardized IPP programme or pre-determined feed-in-tariff. The current practice also restricts sale of power produced by IPPs to anyone other than EEP. There is no regulatory mechanism to allow potential IPPs to generate power primarily for their own consumption (such as captive power plants at industrial sites) or to sell to bulk users (such as industrial facilities or even cities). Neither is there a provision to enable individuals or entities to install embedded generation (for example, on-site generation through rooftop solar PV) and then sell the excess back to the grid.

Modifying such regulatory frameworks would help accelerate the development and deployment of non-hydro renewable energy. For instance, sugar estates or other agricultural estates could set up co-generation plants (based on bagasse as a feedstock) where they could produce power for their own consumption and sell any excess to the national grid, particularly if net metering were introduced. Cities too could benefit if regulations were to allow them to generate power for local use, harnessing available resources. Cities could use such energy to meet local needs, bridge any deficit from the national grid, and then have an additional revenue stream through power sales back to the grid in the case of excess generation.

A role for energy efficiency: In the power sector, a key priority should be to improve energy efficiency and reduce waste (such as transmission losses), even as the government works to facilitate the growth of renewable energy. Energy efficiency is often the least-cost option for meeting energy service requirements. While discussions of energy efficiency are less relevant in the household sector, where power consumption is extremely low and there is much room for energy services to be scaled up, the industrial sector in Ethiopia would be well served by investments in process efficiency and more efficient end-use devices (for example, heat recovery and better kilns in cement factories, improved kilns and stoves in small enterprises, improved cook stoves in commercial establishments like hotels and restaurants). Returns on investment in energy efficiency or energy-efficient appliances are typically fairly rapid, making this an attractive option.

Financial viability of alternatives: Low-carbon energy options are capital-intensive and come with high up-front costs, but oftentimes they are competitive with conventional systems on a life-cycle basis. To overcome the barrier of high up-front costs, access to credit or affordable financing is an important factor. Unfortunately, in many least developed countries, low-carbon technologies do face financing hurdles because the market and regulatory environment are not ready to address their characteristics. For markets to allow better financing, there needs to be more experience with renewables. The first step towards this is better information availability and actionable data, such as through robust resource assessments. Decision makers also need to receive more information about technological maturity and the full range of lifetime benefits. Once Ethiopia opens up its market to IPPs, initial projects may have to be financed on the balance sheets of investors (equity financing). However, as lenders start seeing results and the market matures, there will be greater scope for debt financing from banks and other financial institutions.

Different types and sources of financing are required to address the market and regulatory barriers outlined above. Financing for market readiness and regulatory reform activities can be provided by the government and international development agencies (such financing is already being used to evaluate renewable energy resources in Ethiopia and to build the regulatory capability in the national energy regulator, the Ethiopian Energy Authority). It is plausible that with the right regulatory framework and financial powers, secondary cities could also finance such market-readiness activities with the help of donor agencies.

Financing for small-scale decentralized systems (such as improved stoves for households), on the other hand, should address the needs of both small and micro-enterprises (producers and suppliers of the stoves) as well as consumers. Because of the small size of the financing required for such projects, micro-finance institutions might be well suited to meeting these needs. There are already examples in Ethiopia of development finance institutions providing low-interest finance to enterprises and consumers in the form of small loans, channelled through larger funds.

Commercial banks and multilateral finance institutions are expected to be the main sources of financing for low-carbon technologies in the medium to long term. To ease their entry into lending for low-carbon technologies, development partners have begun providing capacity building support to a few Ethiopian banks (in areas such as market research and technical capacity) and have started providing capital with risk-sharing arrangements (so that banks will not seek exceedingly high collateral from investors).

All these developments are at an early stage in Ethiopia, and continued financial as well as technical support, coupled with strong research and market intelligence support, will be needed to assist Ethiopia in making a successful transition to a green, low-carbon energy future.

Role of low-carbon energy solutions in contributing to economic growth: Cities in Ethiopia would be well served by better understanding how active measures to grow a renewable energy industry in the area could help income generation and wealth creation in urban communities involved, for example, through the creation of new value chains (such as trained technicians for installation and maintenance of renewable energy units).

Role of cultural versus policy drivers in Ethiopia's energy sector: While policy interventions (likely at the central level) are needed to keep low-carbon energy sources competitive in Ethiopia against ever-cheaper fossil fuels, the role of policy and financial incentives may not be adequate to create a change in personal preferences that are heavily influenced by tradition.

7.1. Potential actions in Ethiopia to support stronger energy services in cities (to underpin inclusive growth)

The principal finding of this research project has been that Ethiopia's current power sector market structure and decision-making regime need to undergo change if secondary cities are to have some agency in determining or even influencing their energy mix.

While such regulatory transformation needs to be well planned, and both central and local governments need to be strongly capacitated to make such a change effective, there are a host of other actions that can be taken even while the larger transformation takes the time necessary.

Some examples of potential actions that can support low-carbon energy growth and enhance the ability of electricity access to support inclusive growth are as follows:

<u>At the National Level</u>

- **Strengthening the existing national grid**: This research project revealed that most secondary cities in Ethiopia are connected to the grid. However, the quality of grid infrastructure has been questionable in many locations. Grid upgrades enhancement will not only help make the current power supply (largely hydro, and thus low-carbon) more consistent and reliable, it offers an opportunity to modernize the grid to enable the uptake of more intermittent renewables like wind and solar.
- **Improved O&M of the grid**: One of the more oft-quoted reasons for the lack of reliability of the current power system is the poor condition of the grid. Protecting grid-infrastructure to prevent transmission losses and other inefficiencies, and improving O&M will help the grid remain more stable. With more reliable electricity supply, residents of secondary cities are likely to increase their reliance on electricity-based energy services beyond just lighting.

- **Investment in critical research**: It would serve the Ethiopian national government well to invest in further research regarding low-carbon energy options for Ethiopia, and particularly its growing secondary cities, in light of climate change. It could allocate funds for such research but prioritize the leveraging of international donor funds and support to commission and conduct such research. A stronger knowledge base will allow for more informed and effective decision making about low-carbon energy growth.

<u>At the Regional and Municipal Levels</u>

- **Strategic spatial planning**: The long-term resource efficiency of cities is dependent on their spatial development. And it is important to ensure that the planning get this right while the cities are undergoing rapid expansion. More compact settlements with mixed land use that provide citizens with access to jobs and services without the need for long commutes can avoid a degree of lock-in to a resource-intensive spatial form. A carefully planned city can reduce long-term energy demand, particularly from transportation, thereby reducing reliance on fossil fuel imports and improving energy security.
- **Low-carbon and resource-efficiency-based urban planning**: As noted in the beginning of this monograph, urban planning occurs through two main planning processes within Ethiopian cities: first, the creation of the city-wide master plan, and second, the creation of local development plans at the sub-city level. Both are informed by the national urban development scheme. Local development plans are, in effect, the implementation plans of the master plan. As these plans have influence, and considerable effort is put into developing them and using them to guide local development initiatives, cities should ensure that they are developed with a climate-resilience and resource-efficiency lens.
- **Off-grid feasibility assessments**: Regional and local governments in Ethiopia could investigate the viability and cost-benefit balance of off-grid applications for their urban populations. Several such off-grid options are feasible from a regulatory point of view even today, without the need to wait for legal reforms (for example, solar rooftop water heaters, or a local micro-grid connected to a biogas digester such as one that is already being constructed in Addis Ababa). Cities must bear in mind, however, that even as they explore adoption of off-grid applications like solar water heaters, this scale-up

does not end up disproportionately benefiting the wealthy while perpetuating energy poverty within under-served communities.

- **Creation of incentive frameworks**: Even within their existing fiscal powers, regional governments could investigate the design and introduction of economic incentives for locally based industries to invest in captive generation from renewables, as well as improved biomass combustion for industrial thermal energy.
- **Energy-efficiency codes:** Regional governments and cities could consider the development of guidelines or policies for energy efficiency in buildings. Energy efficiency codes and green building design guidelines could be developed to ensure that new buildings make the most of currently available technologies and designs to reduce their energy need. Building smartly at the outset avoids the need for costly retrofits of efficiency measures later. Such efforts should, of course, be harmonized with any national codes and guidelines.

At the Household Level

- **Improved awareness**: Community organizations could help create more awareness within households, particularly among women, of the benefits of cooking with cleaner fuels. More personal education about available alternatives and a better understanding of health impacts of cooking with traditional biomass could help accelerate the shift towards modern cooking methods.

7.2. Need for additional research

The benefits of developing low-carbon energy sources are numerous, but in the case of Ethiopia an accurate estimation of such benefits necessitates a range of further research and assessments that is beyond the scope of the current inquiry. Critical future research areas that would aid robust analysis of the issues dealt with in this monograph, while gauging the potential tangible and intangible benefits from clean energy for inclusive growth in secondary cities, include (but are not limited to) the following:

a. More localized and country-specific climate change projections, based on a richer network of hydro-meteorological stations, more robust and reliable data, and with higher resolution.
b. Energy demand projections based on modelling that factors in future climate change impacts such as rising temperature on demand for space-cooling, electrical system load and stability.

c. An investigation into the urban development agenda in Ethiopia, including an analysis of the prevailing urban planning paradigm in Ethiopia. Such research could help identify how low-carbon development could be mainstreamed into urban planning to ensure that cities develop in a resource efficient manner. This would strengthen the case for a diversified and low-carbon energy mix while addressing developmental challenges in a more sustainable manner.
d. A comprehensive needs assessment to support the development of a national renewable energy policy (which would further current efforts to research the impacts of a standardized IPP framework and a feed-in-tariff).
e. A sociological and statistical study to understand better why households in Ethiopian secondary cities that have access to affordable grid-based electricity still do not choose to use electricity for cooking and continue to rely on biomass.
f. Economic analysis of benefits (health, environment, social welfare) from low-carbon energy use in cities, including economic externalities.
g. An investigation of low-carbon energy financing options for cities in Ethiopia and comparative models from other African cities to understand future financing options better.
h. Economic opportunities for cities (potentially a cost-benefit assessment and a detailed feasibility assessment) such as employment, derived from a scaling up of low-carbon energy sources.
i. A grid-integration study to determine the ability of an existing grid to absorb more intermittent renewables.
j. A study to evaluate clean energy options for large industry (such as cement), including captive plants.
k. A detailed study of the effect of subsidies and other government policies on energy costs and electricity pricing, to explore competitiveness of non-hydro renewables in comparison to hydropower and fossil fuels (with and without subsidies, and with a dynamic pricing structure).

7.3. Concluding Remarks

Ethiopia’s energy systems have not kept pace with the growth of Ethiopia’s economy, nor with its accelerating rate of urbanization and anticipated future energy demand.

Ethiopia’s staggering reliance on indigenous biomass is both an environmental and public health concern, as well as an energy security concern (costs of bio-mass have already risen to high levels, given the country's diminishing forest cover and ever-decreasing source of supply). While a long-term shift away from traditional bio-mass use is an important goal, in the short-term biomass will continue to dominate the energy supply. Thus, the resource needs to be carefully harvested, managed and efficiently utilized in a way that does minimal damage to the environment, does not negatively impact the health of Ethiopians (especially women), in a manner that reduces the burden and opportunity costs of time spent using and collecting fuelwood. While rural areas may witness a slower shift away from bio-mass, cities must prioritize such a transition, especially as urban settings allow for greater efficiencies and economies of scale for cleaner alternatives.

Ethiopia's electricity mix is already a strong example of low-carbon power. Hydropower is the dominant source of electricity, and the country has significantly more untapped hydropower potential left to harness. However, hydropower growth should be supplemented with other clean energy options. Low-carbon energy sources such as non-hydro renewables could allow Ethiopian cities to benefit from a more climate-resilient, diversified energy supply. Although the likely impacts of climate change on hydrological variability still require a great deal of additional research, a more climate-resilient energy mix can enhance energy supplies even in the short term, and would bring a range of socio-economic, gender and public health co-benefits. Wind energy in particular has significant potential for complementarity with hydropower resources (especially seasonal complementarity). Small-scale, localized, off-grid or mini-grid applications (such as rooftop solar water heaters and municipal waste-to-energy or biogas plants) are also attractive options for cities in Ethiopia to consider adopting. By supplementing their power use from the national grid, cities can provide greater energy services to residents, and help create more economic opportunities through more reliable and consistent power supply. The grid's broad reach does diminish the argument for large-scale ramp-up of off-grid technologies, and the lack of reliability and the current intermittency of grid-based power provides an argument for cities to supplement their power supply where possible. In doing so, however, they must be careful to ensure that off-grid applications can be consistent with the grid, and can in the future be integrated if necessary (this will avoid obsolescence of off-grid assets in the event of grid upgrades and strengthening).

While Ethiopian cities do not currently make their own decisions about supplementary power supply, they should explore their ability to do so, both within the existing regulatory regime and through potential future devolution of energy-sector powers. City-level management of basic service provision, as opposed to regional- or national-level management, is already in place in the case of water and sanitation services. A similar model whereby the city could play a greater management role in power generation and supply is one worth investigating.

At the national level, the government should actively consider regulatory reform that would on the one hand allow cities and regional governments greater decision making in localized power generation and supply, and on the other hand catalyse private sector involvement in the energy sector. This would include a feed-in-Tariff, market restructuring to allow for IPPs, net metering and embedded generation, and a host of such measures.

Whatever may be the energy supply scenario that unfolds, it is essential that cities grow in a spatially smart and resource-efficient manner with buildings that contribute to climate resilience and infrastructure that avoids lock-in to fossil fuels and to energy or transportation inefficiencies. Strategic and integrated spatial planning, with a greater emphasis on low-carbon growth, is a valuable tool in this context.

With the population of secondary cities like Diré Dawa and Mekelle expected to double in the next 20 years, and per capita consumption of energy expected to rise markedly, it is important that households, by far the biggest consumers of energy in these cities, be provided adequate, reliable, affordable and effective alternatives to carbon-intensive traditional energy sources. Expanded choice of low-carbon energy sources, coupled with more reliable and uninterrupted power at affordable rates, is important for cities across Ethiopia to move towards a low-carbon, climate-resilient energy future.

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APPENDIX A: Additional Data

Table A.1: Value of production and energy expenditure in medium- and large-scale industries in Mekelle and Diré Dawa, 2013 (Source: Ministry of Urban Development, Housing and Construction (MUDHCo), 2015. State of Ethiopian Cities 2015)

Row Labels	Sum of Value of production	Sum of Electricity	Sum of Biomass	Sum of Fuel oil	Sum of Diesel
Dire Dawa	**2,036,494,256**	**26,054,561**	**361,400**	**21,245,278**	**128,964**
Manufacture of articles of concrete, cement and plaster	1,050,544,717	20,556,037		14,877,475	-
Manufacture of bakery products	50,832,869	726,244	361,400	-	68,677
Manufacture of basic iron and steel	6,287,823	6,734		-	-
Manufacture of cement, lime and plaster	705,000			-	-
Manufacture of food products n.e.c.	3,610,156	32,504		-	-
Manufacture of furniture; manufacturing n.e.c.	13,746,666	7,939		-	-
Manufacture of grain mill products	177,162,086	1,688,136		-	-
Manufacture of macaroni and spaghetti	243,668,478	946,222		3,986,996	44,281
Manufacture of non-metallic mineral products n.e.c.	25,032,722	525,049		-	-
Manufacture of other fabricated metal products	13,544,966	85,261		24,463	4,800
Manufacture of plastic products	27,129,532	125,149		-	-
Manufacture of soap and detergents cleaning and polishing, perfumes and toilet pr	300,091,926	359,725		570,293	-
Manufacture of soft drinks & production of mineral waters	15,721,960	330,978		-	-
Manufacture of structural metal products, tanks, reservoirs and containers of meta	2,641,005	43,777		-	-
Manufacture of wearing apparel except fur apparel	1,008,000	3,400		-	-
Production, processing and preserving of meat,fruit and vegetables	5,342,209	48,145		-	-
Publishing and printing services	12,139,735	34,864		-	11,206
Spinning, weaving and finishing of textiles	87,284,406	534,397	-	1,786,051	-
Mekele	**4,094,294,198**	**40,040,787**	**1,190,457**	**19,033,700**	**978,861**
Manufacture of articles of concrete, cement and plaster	35,318,771	129,639		-	791,712
Manufacture of bakery products	17,271,959	17,466	1,186,337	-	-
Manufacture of basic chemicals, except fertilizers and nitrogen compounds	6,876,209	39,413		-	-
Manufacture of basic iron and steel	613,815,330	504,775		2,652	-
Manufacture of cement, lime and plaster	2,085,615,291	34,955,925		17,620,754	-
Manufacture of footwear	8,749,250	97,354		44,400	27,655
Manufacture of furniture; manufacturing n.e.c.	42,722,687	82,925	4,120	18,538	12,200
Manufacture of grain mill products	352,217,446	1,486,243		211,774	-
Manufacture of macaroni and spaghetti	11,210,598	77,476		562,559	-
Manufacture of non-metallic mineral products n.e.c.	37,467,257	312,385		156,113	-
Manufacture of paints, varnishes and mastics	9,446,381	18,052		-	-
Manufacture of paper and paper products	2,784,433	4,238		29,500	-
Manufacture of parts and accessaries for motor vehicles and their engines	477,140,055	1,306,538		-	-
Manufacture of plastic products	14,345,813	52,921		310,675	-
Manufacture of soap and detergents cleaning and polishing, perfumes and toilet pr	898,380	2,809		-	-
Manufacture of soft drinks & production of mineral waters	13,128,306	37,517		-	-
Manufacture of structural clay products	3,570,307	11,223		-	-
Manufacture of structural metal products, tanks, reservoirs and containers of meta	158,008,270	173,803		7,676	-
Production, processing and preserving of meat,fruit and vegetables	97,494,055	663,010		-	143,234
Publishing and printing services	5,896,543	42,984		69,059	-
Spinning, weaving and finishing of textiles	100,316,857	24,091		-	4,060
Grand Total	6,130,788,454	66,095,348	1,551,857	40,278,978	1,107,825

Figure A.2: Distribution of micro and small enterprises (MSEs) per 1,000 inhabitants in cities

(Source: Ministry of Urban Development, Housing and Construction (MUDHCo), 2015. State of Ethiopian Cities 2015)