Urban energy transitions in emerging markets: A case study

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Abstract

Urban centers host more than a half of the global population, accounting for a majority of energy use and energy-related CO_2 emissions globally. While energy is the largest single contributor to global climate change, it is also a critical driver of socio-economic development in emerging countries. Future growth of global energy demand will predominantly come from cities in developing and emerging countries. Sub-Saharan Africa is among the most rapidly urbanising regions of the world, which also experiences the lowest levels of access to electricity.

The aim of this thesis was to identify the main urban energy challenges and barriers for the transition to a sustainable urban energy system in Nairobi, the capital of Kenya, with a focus on the electricity sector. A literature review was conducted on socio-technical transitions in urban energy systems along with the challenges and barriers associated with them. The empirical data for the qualitative case study was collected mainly through semi-structured interviews during a field research period.

Over a half of all electricity generated in Kenya is consumed in Nairobi, where the urban population and its energy needs are increasing. The study found that the main urban energy challenges in Nairobi are the unreliability and inefficiency of electricity supply, high cost of electricity and pollution resulting from the use of unsustainable fuels. Barriers hindering the transition to sustainable urban energy include insufficient institutional capacity at the urban level, low awareness and availability of information on renewable energy and energy efficiency, lack of suitable financing mechanisms and lack of collaboration and communication between key stakeholders.

Keywords energy transition, urban energy systems, emerging markets, sustainable energy, Nairobi, Kenya

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Tiivistelmä

Yli puolet maailman väestöstä asuu kaupungeissa. Kaupungit vastaavat suurimmasta osasta maailman energiankulutuksesta ja siihen kytköksissä olevista hiilidioksidipäästöistä, jotka ovat merkittävin yksittäinen ilmastonmuutoksen aiheuttaja. Energia on myös välttämätön taloudellisen ja sosiaalisen kehityksen mahdollistaja kehittyvissä maissa, joissa valtaosa maailman tulevasta energiankulutuksen kasvusta tulee tapahtumaan. Saharan eteläpuolinen Afrikka on maailman nopeiten kaupungistuvia maanosia, jossa lisäksi sähköistysaste on maailman alhaisimpia.

Tutkimuksen tavoitteena oli tunnistaa keskeiset energiahaasteet sekä esteet kestävään energiajärjestelmään siirtymiselle Nairobissa, Kenian pääkaupungissa, keskittyen sähköenergiasektoriin. Tutkimuksen kirjallisuuskatsaus käsittelee sosioteknisiä muutoksia kaupunkien energiajärjestelmissä sekä niihin liittyviä haasteita ja esteitä. Laadullisen tapaustutkimuksen empiirinen data kerättiin pääosin kenttätutkimuksen aikana tehdyillä haastatteluilla.

Keniassa tuotetusta sähköenergiasta yli puolet kulutetaan Nairobissa, jossa energiankulutus on kasvussa nopean väestönkasvun ja kaupungistumisen myötä. Tutkimuksen tulokset osoittavat, että Nairobin keskeiset energiahaasteet ovat epäluotettava sähkönjakelu ja suuret jakeluhäviöt, korkea sähkön hinta sekä polttoaineiden käytöstä aiheutuvat saasteet. Esteitä kestävään energiajärjestelmään siirtymiselle ovat riittämätön institutionaalinen kapasiteetti kaupunkitasolla, sopivien rahoitusmekanismien puute, heikko tiedon saatavuus ja tietoisuus uusiutuvasta energiasta ja energiatehokkuudesta sekä vähäinen yhteistyö ja kommunikaatio keskeisten toimijoiden välillä.

Avainsanat energiamurros, kaupunkien energiajärjestelmät, kehittyvät markkinat, kestävä energia, Nairobi, Kenia

Preface

There is obviously no adventure without challenge, but this project would have been far more challenging and less adventurous without the contributions of certain people that I would like to acknowledge here.

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To everyone I crossed paths with during the time spent in Kenya, thank you for making it a very special, uplifting and unforgettable period in my life.

I definitely owe a shout-out to my dear friends for making sure that I didn't spend the entire summer indoors working on this thesis. I also really appreciated the fact that you more frequently asked me about the adventures abroad than about the progress with the thesis writing.

Äiti. Isä. Kyllä te tiedätte.

Helsinki, 3.9.2018

Erika Forstén

Contents

Abbreviations and Acronyms

AEPEA	Association of Energy Professionals East Africa
CEEC	Centre of Energy Efficiency and Conservation
CO_2	Carbon Dioxide
ERC	Energy Regulatory Commission
FiT	Feed-in-Tariff
GDP	Gross Domestic Product
GHG	Greenhouse gas
IEA	International Energy Agency
IPP	Independent Power Producer
KAM	Kenya Association of Manufacturers
KenGen	Kenya Electricity Generating Company
KEREA	Kenya Renewable Energy Association
KETRACO	Kenya Electricity Transmission Company
KGBS	Kenya Green Building Society
KCIC	Kenya Climate Innovation Center
KP	Kenya Power
LCPDP	Least Cost Power Development Plan
LPG	Liquid Petroleum Gas
MLP	Multi-Level Perspective
MoE	Ministry of Energy
NGO	Non-governmental Organisation
PPA	Power Purchase Agreement
PV	Photovoltaics
REA	Rural Electrification Authority
SDG	Sustainable Development Goal
SERC	Strathmore Energy Research Centre
SSA	Sub-Saharan Africa
SWH	Solar Water Heating
UN	United Nations
W2E	Waste-to-Energy
WHO	World Health Organization

1 Introduction

This chapter begins with an overview on the topic of the thesis and the background and motivation behind the study. The research questions and scope of the study are then presented, followed by an overview on the structure and contents of this thesis.

1.1 Background and motivation

The global population is predominantly and increasingly urban. Urban centers currently host more than a half of the global population, accounting for two thirds of global primary energy use and 70% of global energy-related CO_2 emissions [1, 2]. By 2050, 65% of the world population will live in urban areas [3].

Energy is the largest single contributor to global climate change, accounting for a majority of global greenhouse gas (GHG) emissions [4]. Currently, exhaustible fossil fuels still cover over 80% of primary energy use globally [2], producing an unsustainable amount of CO_2 emissions that contribute to climate change and have severe and irreversible impacts on the health of people and ecosystems globally [5]. The targets set in the Paris Agreement [6] to keep the global temperature rise below 2°C above pre-industrial levels, while pursuing efforts to limit the increase even further to 1.5°C, require substantial reductions in energy-related CO_2 emissions through improved energy efficiency and decarbonisation of energy systems [2, 5, 7].

The increase in global GHG emissions is driven by economic and population growth [5]. While energy is a major contributor to climate change, it is also an essential driver of socio-economic development in emerging countries. Although industrialised countries have previously accounted for a majority of emissions globally, the future growth of global energy demand and related emissions will be driven by developing countries [7], which are also among the most vulnerable regions to the effects of climate change [5].

As urban energy demand further increases with the growth of the urban population and economic activities, the related emissions are also projected to grow [2]. Therefore, substantial efforts to decouple emissions from development are required, and a fundamental transition of energy systems is critical in order to meet the ambitious global climate mitigation goals.

The widely acknowledged UN 2030 Agenda for Sustainable Development defines 17 Sustainable Development Goals (SDGs) to provide a global agenda for sustainable development. SDG 7 aims to "ensure access to affordable, reliable, sustainable and modern energy for all". In addition to universal access, it also includes targets to substantially increase the share of renewable energy in the global energy mix and double the global rate of improvement in energy efficiency by the year 2030. Sustainable energy can also contribute to the health of people and the environment, economic growth and job creation as well as social inclusion and gender equality [3, 5, 7], thus also prominently contributing to SDG 11 that aims to "make cities inclusive, safe, resilient and sustainable". [8]

While sustainable urban energy is in an essential role for the global efforts to mitigate climate change, it also has significant importance for developing countries in terms of resilient economies, health of people and ecosystems and poverty alleviation [7]. Cities drive the increase of global energy demand and its impacts, but the potential for cost-effective sustainable energy solutions in cities is also significant. The high population density and economic and human resources concentrated in cities provide unique opportunities for more integrated and efficient systems, infrastructures and use of resources [2].

Sub-Saharan Africa (SSA) is among the most rapidly urbanising regions of the world, which also experiences the lowest levels of access to modern energy and high rates of poverty [9, 10]. The bulk of population growth in Africa occurs in cities, even when the migration from rural areas to cities is not taken into account. Cities place heavy demands on urban services, but the capacities to deal with these pressures are generally insufficient and the urban settlements vulnerable. Additionally, rural-to-urban migration is expected to increase significantly due to the environmental impacts of climate change. [11]

While urbanisation can drive economic growth and well-being through improved access to jobs, services and housing, urbanising populations in SSA face a variety of sustainability challenges related to energy. Rapid growth of urban population, the increasing demand for urban services and the already felt effects of climate change further complicate the energy and sustainability issues faced in the region. In order to reduce the energy intensity and carbon emissions related to socio-economic growth, pursuing sustainable urban energy paths is necessary. However, several barriers still hinder energy transitions in cities of emerging countries.

The aim of this thesis is to identify the main urban energy challenges and barriers for the transition to a sustainable energy system in Nairobi, the capital of Kenya. Over 50% of all electricity generated in Kenya is consumed in Nairobi [12]. Although Nairobi is already mostly covered by the national electricity grid, there are still major issues related to the provision of clean, reliable and affordable energy. Previous literature on urban energy systems has focused on cities of the industrialised countries, whereas the urban regions of emerging countries are characterised by different energy challenges. While energy systems are typically assessed on a national level, this study focuses on the urban level, drawing on the above described significance of sustainable urban energy in terms of climate change mitigation and socio-economic development in emerging countries.

1.2 Research objectives

This thesis studies urban energy transitions in emerging markets with a case study of Nairobi, Kenya. The aim is to identify the urban energy challenges and barriers that hinder the transition to sustainable energy in Nairobi.
The thesis will propose answers to the following research questions:

1. What are the main urban energy challenges in Nairobi?

2. Which barriers hinder the transition to a sustainable urban energy system in Nairobi?

To achieve the research objectives, a literature review is conducted on socio-technical transitions, urban energy systems and barriers to renewable energy and energy efficiency. A qualitative case study is conducted, for which the empirical data is collected mainly through semi-structured interviews during a field research period.

1.3 Definitions and scope of the study

Several definitions for sustainability and sustainable energy exist. The World Commission on Environment and Development defined in 1987 that "sustainable development" is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" [13]. Sustainable development must therefore be powered by sustainable energy. For the purposes of this study, sustainable energy is defined as clean, reliable, accessible and affordable energy. As means for achieving a more sustainable energy system, the study discusses the aspects of renewable energy and energy efficiency. The focus of the study is on the electricity sector, while other constituents of urban energy systems, such as cooking fuels and transportation, are discussed briefly. Embodied energy use from the purchase of goods and services whose energy consumption occurs outside Kenya is not taken into account. The study constructs a holistic view on the topic of sustainable urban energy in the case context by combining techno-economic and socio-technical approaches.

An emerging market, country or economy can be defined in multiple ways. The World Bank classifies countries based on their economic status into low-income, lower-middle-income, higher-middle income and high-income countries, of which the three first categories can be referred to as developing countries [14]. In this study, the terms developing and emerging are used interchangeably. In the same context, the terms country, economy and market are used interchangeably. The concept of development is used here to broadly refer to sustainable socio-economic development without further discussing various paradigms of development.

1.4 Structure of the thesis

This chapter introduced the background and motivation behind the study, followed by definitions of the research problem and the scope of the study. Chapter 2 presents the theoretical framework for the study, establishing a basis for understanding socio-technical transition processes, urban energy systems and previously identified barriers and hindrances to the adoption of renewable energy and energy efficiency technologies especially in the context of emerging markets. Chapter 3 describes the methodology used for the study, covering research design and the methods used for data collection and analysis along with their limitations. Chapter 4 explains the context of the case study. Chapter 5 presents the findings of the study, which are then discussed and reflected on in relation to the theoretical framework in Chapter 6. Concluding remarks and a summary of key results are presented in Chapter 7.

2 Literature review

In this chapter, main theoretical concepts related to urban energy transitions and barriers to sustainable energy in emerging markets are presented based on previous literature. First, the multi-level perspective (MLP) on socio-technical transitions is presented as a framework for understanding the dynamics of change and stability in energy system transitions. The positioning of the electricity sector and the urban scale in relation to the MLP are also discussed. The characteristics and components of urban energy systems are then introduced along with common challenges associated with them. Finally, factors that have previously been identified as barriers for renewable energy and energy efficiency are presented.

2.1 Multi-level perspective on transitions

Energy transitions are large-scale changes that involve a variety of actors and processes in several geographical dimensions and levels of socio-technical systems. Theories on socio-technical transitions seek to provide understanding on the change processes involved in such transitions and how they occur in complex contexts.

Technological transitions are not only realised by new and evolving technologies, but also changes in other mutually interlinked and co-evolving elements of the socio-technical system, such as user practices, regulatory frameworks, industrial networks and infrastructures [15, 16]. Socio-technical transitions can be defined as large-scale reconfigurations or transformations in the ways society works, concerning key functions such as transportation, communication and housing [15], as well as energy systems. The term transition is also commonly used interchangeably with the terms "systems innovation" and "systemic change" [17].

The multi-level perspective (MLP) is a widely adopted analytical framework for studying the dynamics of change in transitions of socio-technical systems [15], which has been used in both theoretical and empirical studies on energy transitions [18, 19]. It seeks to explain how established socio-technical regimes are reshaped by internal processes, technological niches and wider socio-technical pressures, taking into account the socially constructed nature of technological systems.

The MLP distinguishes a nested hierarchy between three levels of a socio-technical system: socio-technical landscape (macro-level), socio-technical regime (meso-level) and technological niches (micro-level). According to Geels [16], socio-technical transitions are profound reconfigurations of socio-technical regimes, occurring through interactions between the three levels of the socio-technical system.

Socio-technical landscape at the macro-level is the broader context, which consists of deeply rooted cultural values, norms and other macro-level situations. The socio-technical landscape exerts external pressures on the regime and niches. The landscape typically changes slowly and is difficult to affect from the lower levels of the socio-technical system. [16, 17]

Socio-technical regime at the meso-level is formed by established rules, knowledge, routines and assumptions that are embedded in existing institutions and infrastructures. The predominant technologies, rules and practices provide stabilising

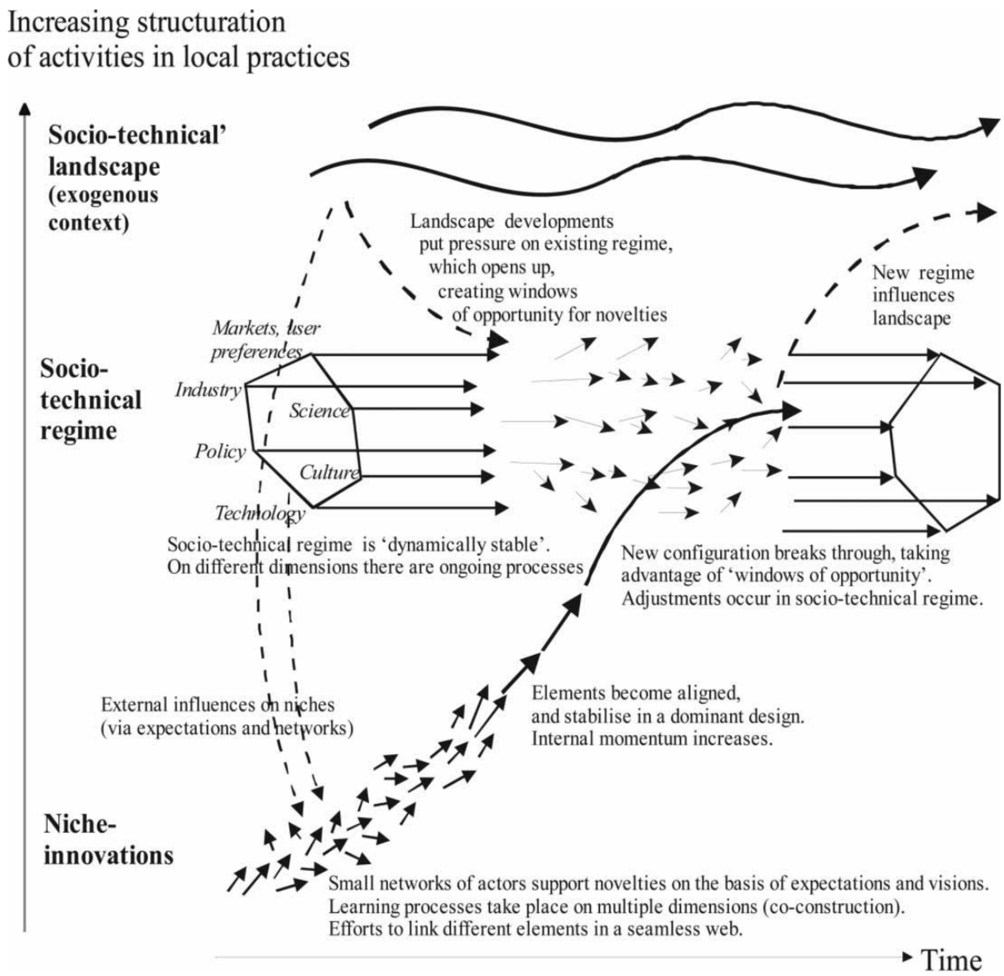

Figure 1: Multi-level perspective on socio-technical transitions [16].

mechanisms which reinforce the existing regime. A characteristic of the regime is its resistance towards change. [16, 17] The establishment of socio-technical systems is based on the linkages between their elements, which result from the activities of involved institutional, industrial and other groups. These groups share similar aligned and coordinated practices, which sustain the the technological regime. [15, 16]

Technological niches are formed at the micro-level of the socio-technical system. Niches are spaces for experimentation, incubation and new innovation, restricted from major market competition and regulation [16], with resources often provided by public subsidies [20]. Protection is needed, since the price/ratio performance of new technologies is typically low [20]. There is generally less organisation and coordination in the activities of niche actors than among the regime actors. Niches enable the formation of networks and interactions between innovation-supporting actors. [16, 17]

Transitions happen through interactions between the levels of a socio-technical system. Figure 1 is a simplified illustration of the transition dynamics between the three levels. Changes at the landscape level create external pressures on the existing regime and niches. At the niche level, novelties gain momentum through mainly price/performance ratio improvements, learning processes and support from influential actors. Destabilisation of the regime can create "windows of opportunity" for niche innovations, enabling them to merge into the regime level. [16] Profound transitions can occur when the three levels are aligned and reinforce each other, and different timings of interactions may lead to different outcomes in transition paths [16, 20].

There are several mechanisms of stabilisation at the regime level, including regulations and standards stabilising the regime, vested interests of regime actors and sunk investments and technical structures of existing technological systems. The rules and routines embedded in the regime may also "blind" the actors from developments outside the regime trajectories. Destabilising pressures are exerted on the regime from both landscape and niche levels. [16, 20]

Niches and regimes are similar kinds of structures formed by communities of interacting groups, but in regimes, the communities are large and stable, whereas niche communities are typically small and unstable [16]. Generally, technological variety and disruptive innovation are generated in niches, while regimes support the generation of stabilising incremental innovation. Niches provide facilities for learning processes through doing, using and interacting as well as for building social networks in the innovation value chain. [15] Niche actors support novelties based on their expectations and visions on them. Niches and regimes develop through the endogenous processes of social-institutional (e.g. rule negotiation) and evolutionary-economic (e.g. market selection) change. [16]

The socio-technical landscape is a different type of structure from the socially structured fields of regime and niche. The landscape provides a rooted external context that actors typically can only influence in the long term. Landscape developments are imposed by macro-level factors such as economical, political, cultural and environmental change, but also rapid external shocks, such as wars or environmental catastrophes. [16]

The definition of the existing regime depends on the system that is being studied, and a regime shift at one level might be considered as an incremental change at another level [16]. Energy systems can be studied on various spatial scales, such as globally or nationally, and in various dimensions, such as at the level of the entire system from resource extraction to end use or at the level of the electricity distribution system.

In the electricity system, the socio-technical regime can be viewed to consist of three main dimensions: 1) the material and technical configurations of the system, such as grid infrastructures and power generation facilities, 2) the networks of actors and social groups, such as utilities, users and governments, and 3) the regulative, normative and cognitive rules guiding the activities of the actors. Path dependency and lock-in are characteristic to electricity regimes as a result of stabilising mechanisms in all of the three dimensions. [20] Due to this inertia in the regime, technology dominance is hard to disrupt and large changes tend to take time.

While transition studies rarely address the spatial scale of transitions, urban studies have attempted to include this aspect in the analysis of urban transitions, which involve spatial relations between the local, national and international levels [9]. Due to the multi-scale interlinkages, urban transitions cannot be comprehensively analysed in isolation at the local scale. Urban systems are affected by governance at national and local scales, while energy systems, politics and economics are strongly influenced by national and international scales. Transitions on urban, district and household scales are often categorised as niches or sites for niche activities in socio-technical transitions, although especially large cities and capitals often have privileged positions in the national regime structures [9, 19]. Cities and regime changes at the local level have been noted their ability to facilitate change on also national and regional levels, as initiatives for energy efficiency, the use of renewable energy sources, sustainable transportation and sustainable buildings are often implemented first at the urban level [19].

2.2 Urban energy systems

More than half of the global population already live in urban centers and the urban population is growing at an increasing pace, especially in the developing world. Urban centers account for a majority of final energy use and energy-related carbon emissions globally. [1] The urban regions of Sub-Saharan Africa face specific energy challenges with the fast urbanisation rates, high amount of poverty and low levels of electrification [9, 10].

Urban energy systems are complex entities with vague, context-dependent boundaries. Therefore, this section begins by defining urban energy systems, explaining the main components comprising an urban energy system and their interrelations with each other. Next, characteristics and specifics of urban energy use are presented, followed by an overview on typical urban energy challenges with a focus on urban regions in emerging markets.

2.2.1 Definitions

Generally, an urban energy system includes all the components related to the provision and consumption of energy services in an urban area. International Energy Agency (IEA) and World Resource Institute (WRI) [21] define urban energy systems as "the sectors and processes needed to satisfy the energy service demands of an urban area", in addition to which a sustainable urban energy system also promotes economic and social development, health of the environment and the human population and accessible, affordable and reliable energy.

Energy systems are traditionally assessed on a national level, while specific characteristics of urban energy systems include the high density of population and the high energy use and pollution resulting from its activities. Natural resource extraction and electricity generation generally happen outside urban areas, while the use of electricity and other resources is concentrated in cities. [1, 22] Urban energy systems are embedded in other sectors of an urban center, and therefore changes in urban infrastructures and systems are interlinked and constantly co-evolving processes. Urban energy transitions cut across a variety of policies, processes and

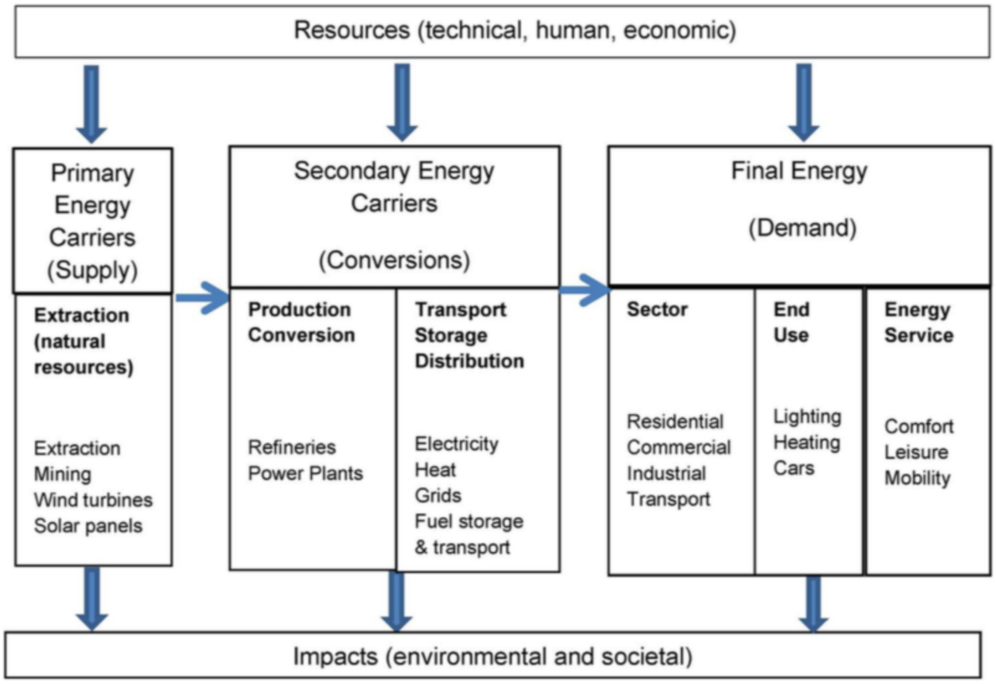

Figure 2: The components of an urban energy system [23].

practices and are multispatial and multitemporal by nature. [22]

An urban energy system (Figure 2) can be viewed to comprise of energy supply and sources (primary energy), energy conversion, distribution and transmission (secondary energy) and energy use and demand (final energy). Technical, human and economic resources are required for the provision of primary, secondary and final energy, which result in various environmental and societal impacts. At the urban level, the end use of final energy occurs mainly in residential, commercial, industrial and transportation sectors, providing various energy services for residents and businesses in an urban area. [23]

2.2.2 Urban energy use

Energy is the largest single contributor to global climate change [4], while the global population and its energy use are predominantly and increasingly urban [2]. Urban centers currently host more than 50% of the global population, accounting for estimated 64% of primary energy use, 60–80% of final energy use and 70% of global energy-related CO_2 emissions [1, 2]. Because energy use is concentrated in cities [1], identifying the associated urban energy challenges requires an understanding on how energy is used in urban areas.

According to IEA [24], global final energy consumption in 2015 was 9 384 Mtoe in 2015, of which 18.5% was consumed as electricity, while oil and coal accounted for a half of all final consumption. The African continent accounted for a share of 6.1% of global final energy consumption and 3.6% of CO_2 emissions resulting from fuel combustion. IEA also predicts that two thirds of the growth in global energy demand to 2050 will come from cities in emerging and developing countries [2].

By 2050, 65% of the world population will live in urban areas [3], while intensive energy use is already an integral part of urban structures and modern urban societies are heavily dependent on energy [22]. Urban energy demand is further increasing due to the growth of urban populations and economic activities. The increase is projected to be driven dominantly by the growth of developing countries [2, 7], where urbanisation also enables access to modern energy and improved standards of living.

In developing countries, the energy use per capita of urban residents is considerably higher than those of rural dwellers, which reflects the stark contrast between the income levels of urban and rural areas, as characteristic for developing countries. On the contrary, in industrialised countries the energy use per capita of the urban population is lower than the national average, resulting from factors such as efficient transportation infrastructures and more energy efficient settlement types. [1]

The energy use of urban areas involves multiple spatial scales. Locally, energy use consists mostly of housing, transportation and industrial activities. Embodied energy is used indirectly through the purchases of services and goods whose energy use occurs outside the area of consumption. [1] In the long-term, the energy use of an urban area is typically defined more by systemic characteristics than for example individual users or technologies [1], although new consumption habits and technologies generate new niches that can have a reshaping effect on the socio-technical landscape of urban energy [9].

While cities in emerging countries drive the increase of global energy demand and its effects, they also hold significant potential for cost-effective sustainable energy solutions. Cities in emerging countries can still avoid the lock-in to carbon-intensive and inefficient forms of several urban centers in developed countries, while achieving significant socio-economic benefits without compromising access to modern energy services. Globally, cities can deliver 70% of the cost-effective CO_2 reduction potential required by 2050. [2]

At the macro-level, the energy use of an urban area is the result of economic activities, infrastructure and urban planning, human activities and consumption patterns as well as local climate and geographical conditions [23]. Key factors affecting urban energy efficiency include urban form and density, energy efficiency of the built environment and urban transport systems, followed by energy system integration measures [1]. High population density, concentration of economic resources and availability of local expertise provide opportunities for more integrated and efficient systems, infrastructures and resource streams in cities [2].

Urban centers have significant potential for energy efficiency improvements, whereas the significance of local supply-side measures is limited. As local renewable energy supplies are typically low compared to the concentrated population and energy demand of urban areas, locally harvested renewables can provide a relatively small share of the energy needs of larger cities. Rooftop solar PV and solid waste are typically the most potential cost-efficient options for local electricity generation in urban areas, while various distributed and integrated resources and grid topologies, including electricity storage, may enable significant flexibility to the urban energy system. [1] Urban energy systems can host the critical niches for innovative energy technologies [2], and the implementation of new environmental, technological and societal innovations is commonly initiated in cities [1].

2.2.3 Urban planning and policymaking

Policies affecting urban areas typically involve several levels of governance, and the relevance of national policies to urban energy systems varies between cities [1]. While national policy frameworks are important enablers of sustainable energy development, policymaking at municipal or local level may allow faster implementation and more ambitious renewable energy and energy efficiency goals [7]. Integrated responses to energy and urban planning on the local level may also facilitate improved resilience, emission reductions and sustainable development on the broader geographical levels [2, 5].

The capacity and regulatory power of local governments is often insufficient for the implementation of efficient policies for sustainable energy. Support from national governments is instrumental in facilitating sustainable energy transitions in cities. National governments can accelerate urban energy transitions by setting enabling frameworks and regulatory measures, such as requirements for cities to introduce local energy plans and energy efficiency standards. Capacity building and financing schemes are important in cities of emerging countries, where national governments and international development organisations may have an enabling role in urban energy transitions. [2]

Sustainable urban energy policies are often systemic by nature and involve integration of different processes, such as planning of land-use and urban transport, or resource streams, such as heat recovery and waste-to-energy (W2E). Although systemic policies tend to be more effective in the long-term, such integrated measures are often difficult to design and implement. [1] They require coordinated effort and decisionmaking, and can therefore be hindered by weak institutional capability, as local administrations often lack the legislative, financial and human capacities to implement efficient policy approaches [2, 9].

The urban form and density of cities develop over time. Therefore, their evolution is path dependent, leading to different availability of options for improvements in energy efficiency and sustainability. Integration of various urban services can have a significant effect on the efficient energy use of an urban area. [1] However, stakeholders of urban regions tend to work individually rather than together, which typically results from weak or disconnected institutional frameworks [21]. Integrated approaches can be designed in city master plans, but it is challenging to maintain such integrity in the implementation phase [1]. As energy and sustainability challenges are becoming increasingly prominent globally, several cities have developed local energy plans and policies [21].

The alignment between local and national energy policies is linked to the success of energy measures and goals on both levels [2]. Integration is required horizontally, across various urban energy stakeholders, as well as vertically, across local and national governance. However, existing urban energy policies and frameworks tend to focus on narrow issues and lack a comprehensive view of the overall urban system as well as the interrelations between the different constituents of an urban system. [21] In addition to public administration of cities, land owners and public or private utility service providers significantly influence the development of urban services within a city [1]. The establishment of institutional basis enables strenghtened coordination and dialogue between national and local governments and other energy stakeholders, which increases their ability to identify urban energy challenges and find locally relevant solutions to accelerate the urban energy transition [2].

Holistic approaches to urban issues are hindered by several institutional and systemic issues. Urban governance is often fragmented, with the complexity and scale of cities leading to a multitude of specialised departments and institutions responsible for particular subsectors of an urban system. The siloed operation of urban governance can fail to provide incentives and institutional support for cross-sectoral and holistic approaches for decisionmaking at the urban level. In developing countries, low availability and reliability of required data often hinders informed and systemic approaches to urban decisionmaking. [25]

2.2.4 Urban energy challenges

The growth of the urban population in emerging countries is associated with persistent sustainability challenges and difficulties in the provision of basic services, such as housing, water, sanitation, transportation, waste management and energy. The challenges faced by urban regions are projected to be amplified by population growth and the changing climate. Especially in developing countries, urban areas are expected to experience increased risks from heat stress, extreme weather events, flooding, droughts and air pollution. [1, 5] The energy challenges in urban regions of Sub-Saharan Africa are specifically affected by fast urbanisation rates, high poverty rates and low levels of electrification and access to modern energy [9].

A majority of the population growth in SSA happens in cities, even without taking into account the migration from rural to urban areas. Cities place heavy demands on urban ecosystems and services, while the institutional, financial and human capacities are generally insufficient in order to deal with these pressures. Additionally, the rural-to-urban migration is expected to increase due to the impacts of climate change on the environment. [11]

Uneven distribution of urban services and infrastuctures is common in SSA, where urban forms have been affected by colonial and post-colonial regimes and class inequality [9]. In several cities, the unmanageable growth of the urban population has resulted in the formation of informal settlements, which are often located in the peri-urban areas. Service provision becomes difficult especially for the urban low-income residents, who commonly live in informal settlements not reachable by modern infrastructures and services. [3] Urban dwellers in informal settlements often lack access to electricity, clean cooking fuels and transportation [1]. While the need to meet the basic service demands for the urban poor is rising, the urban energy systems in SSA are also affected by the changing consumption patterns due to the growth of the middle-income population [9].

Energy directly affects the health and quality of an urban environment in the form of air pollution and urban heat island effects [23]. Therefore, the high density of energy demand in cities implies a need for low-emission energy systems [1]. Urban populations are affected by several sources of air pollution, which is a severe challenge in urban regions worldwide. Only 12% of the world's urban population lives in cities that comply with the air quality guidelines of World Health Organization (WHO) [3], which estimates that 3.3 million people die annually from exposure to fine particulate matter. Vehicle emissions are a significant contributor to fine particulate matter in urban ambient air. Additionally, WHO estimates 4.3 million annual deaths due to household air pollution, resulting from the use of polluting fuels for cooking. Improved access to clean cooking fuels and efficient cooking stoves can significantly decrease urban pollution and its harmful health effects [3], but cleaner and safer cooking fuels are often not available or affordable for especially the urban poor, who rely on fuels such as charcoal, wood and kerosene [1, 9].

Energy poverty in low-income countries implies lack of access to electricity and the use of cheapest fuels and equipment, such as kerosene lighting and inefficient cooking stoves, which have harmful effects on indoor air quality, safety and health. In the whole SSA, an estimated 120 million urban residents lack access to electricity. Innovations in low-income energy provision, such as pay-as-you-use metering, low tariffs for "lifeline" electricity use and boards removing the need for connecting individual houses, have enabled access to an increasing amount of low-income end users through decreased costs. [1]

In addition to electricity access, the quality and consistency of supply is a common challenge in developing countries. Urban areas are typically dependent on grid-based infrastructures [1], while developing countries commonly face issues with the reliability of the grid infrastructures and rely on co-existing informal and off-grid sources of fuels and energy services [9].

2.3 Barriers to sustainable energy transitions

This section presents barriers hindering the adoption of renewable energy and energy efficiency that have been previously identified in literature. The focus is on barriers relevant to emerging markets.

Renewable energy and energy efficiency are in a critical role in the energy sector transitions of developing and emerging countries [7]. Energy efficiency measures can significantly reduce emissions caused by the use of fossil fuels, and improving efficiency is among the most important means of transitioning to sustainable energy in cities [1, 26]. Still, wide gaps exist between potential cost-effective energy efficiency measures and the measures actually being implemented. From a techno-economic perspective, the barriers causing the gap can be defined as mechanisms that hinder investment in renewable energy and technologies that are both cost-effective and energy efficient. [26] Taking the approach of the MLP introduced earlier, the barriers can be viewed as mechanisms that stabilise and enforce the unsustainable practices embedded the existing socio-technical regime, or factors that frustrate relevant niche innovations from gaining momentum.

In literature, several ways of categorising barriers exist. Here, the barriers are categorised in five groups: insitutional and regulatory barriers, economic and financial barriers, market related barriers, technological barriers and socio-cultural barriers. The classification of barriers to categories is fluid and not unambiguous, as some of the barriers can actually belong to several categories, and the interrelations between the causes and consequences of the barriers in practice are complex [26]. The term sustainable energy is used to cover both renewable energy and energy efficiency solutions, where applicable.

2.3.1 Institutional and regulatory barriers

Governments in emerging countries have increasingly implemented policies and targets to adopt renewable energy and energy efficiency technologies. National goals, sector-wide planning as well as direct and indirect policy support are some of the means available for policymakers at different levels of governance to enable and encourage the adoption of sustainable energy technologies. [7]

Lack of institutional support and enabling policy frameworks. Institutional support and enabling policy frameworks across relevant levels of government are a key prerequisite for the successful development and adoption of sustainable energy solutions. Lack of enabling legal frameworks, weak innovation support systems and market policies to encourage investment and private sector participation can be a major hindrance for the development and adoption of sustainable energy solutions. [27, 28] Enabling policy frameworks for energy efficiency often include measures such as standards and labels or energy monitoring and auditing programs, while renewable energy is typically encouraged through feed-in-tariffs, tendering and net metering [7].

Highly controlled energy sector. High amount of government control and monopolies in the energy sector can be classified as institutional barriers, because when the market is controlled by a few large players, regulations and policies tend to be designed to protect the dominant centralised production [27], i.e. to stabilise and enforce the existing regime. Policies designed according to monopoly or near-monopoly systems may prevent the market entry of independent power producers and the integration of decentralised solutions to power systems, which in turn hinders new investment and development in the sector [28].

Lack of intellectual property rights. Lack of protection and monitoring of intellectual property rights can hinder private investment in research and development activities, when exclusive property rights cannot be used for the benefit of initiators [28]. This negatively affects the groups operating in socio-technical niches, hindering new technological innovation.

Lack of stakeholder involvement. Lack of stakeholder involvement in decisionmaking can lead to inefficient policies, as the resulting decisions might be based on mismatched priorities [27].

2.3.2 Financial and economic barriers

Financial barriers have been considered a key issue for the adoption of renewable energy technologies in countries that are economically resource-constrained [27].

Lack of access to capital. Lack of access or limited access to capital commonly inhibits the adoption of energy efficiency or renewable energy solutions, which are often more expensive than conventional technologies. Obtaining the capital required for the investments may be an issue due to low liquidity, limited possibilities for lending money or the lack of financial institutions and instruments providing access to capital. [26, 27]

High initial costs. High initial investment costs are a major hindrance for several renewable energy solutions, especially for end users in developing countries [28]. Additionally, high cost of electricity, high cost of capital and lack of access to capital or consumer credit can reduce the demand and economic viability of sustainable energy technologies [27].

Perceived risk. Renewable energy projects are deemed more risky than established and conventional power projects, which can hinder investment in the sector. Renewable energy projects in developing countries are also commonly hindered by financial risks due to uncertainties in the future development of electricity prices. A majority of power projects are subject to such risks, while private investors expect high returns for high-risk projects. [28]

Hidden costs. Additionally, hidden costs associated with seeking information, negotiating with sellers, preparing contracts and other activities inhibit investment, as a potential investor might consider such costs higher than the profit from the investment [26].

2.3.3 Market barriers

Market barriers are closely related to the cost of energy solutions and therefore partially overlap with economic and financial barriers. Here, market barriers refer to the additional factors that may inhibit the functional operation of markets for sustainable energy technologies.

External costs. Non-considered externalities, or unpriced environmental impacts, can lower the cost of conventional technologies under appropriate levels, when external costs (negative impacts due to external factors) of emissions are not taken into account in pricing [27, 28]. Subsidies to conventional energy technologies have the same effect, decreasing the competitiveness of renewable energy technologies [27].

Lack of competition. Lack of competition, for example due to state-controlled monopolies in the energy sector, can prevent or hinder the market entry of new actors, keeping product costs high. However, regulated energy network industries, such as regional electricity distribution and transmission providers, are typically natural monopolies based on a least-cost principle. [28]

Trade barriers. Trade barriers, such as high taxes on imports, may increase the prices of available technologies [27].

2.3.4 Technological barriers

Technological barriers are related to the technical and material characteristics or the physical environments of energy systems.

Reliability and performance. Unreliable performance of technologies can be related to site-specific factors, high or unpredictable maintenance costs [29], suppliers' uncompliance with system and product standards or the lack of such standards [27]. However, most technologies on the market are well proven with low risks related to their performance [29].

Infrastructure and environment. Lack of required infrastructure, such as roads and grid connectivity, may act as a technical barrier for renewable energy development [27]. Renewable energy projects might be delayed due to the lack of reliable and accurate site specific data, such as local topographies, wind patterns, solar irradiation or delineation of geothermal reserves, which causes difficulties in modeling the operation of the system, including its output and thus return on investment. [28]

Lack of expertise. Lack of skilled personnel to operate and maintain energy systems is another common barrier in developing countries, which may lack the capacities and infrastructures for training personnel and ensuring their access to required knowledge, technologies and tools. Required tools and parts may also be missing in the first place, when technologies are imported from abroad. [28]

2.3.5 Socio-cultural barriers

Socio-cultural barriers result from social, cultural and behavioural factors affecting the decisionmaking of people. They are related to the availability and quality of information, awareness, trust and social acceptance, cultural values and norms. Socio-cultural barriers, many of which can be associated with the broader landscape level of the socio-technical system, are typically more difficult to change, as rooted cultural norms, practices and values tend to change slowly [16].

Lack of social acceptance. Lack of social acceptance hinders the adoption of sustainable energy technologies, especially when insufficient attention is paid to social, cultural and environmental concerns that are often related to especially hydropower and wind power projects. Promoting awareness and adequate communication may help overcome related concerns. [28] Behavioural barriers and resistance towards change can also stem from consumer perceptions of increased complexity and discomfort of modern energy technologies compared to conventional technologies. Additionally, people tend to take advice from their friends and relatives rather than experts, especially when access to reliable information is insufficient. [29]

Lack of awareness. Lack of awareness of the technologies and their potential opportunities and benefits, as well as the public and institutional awareness of the techno-economic benefits of sustainable energy compared to conventional technologies, can hinder the adoption of sustainable energy solutions. [28] Especially households and small companies may lack access to reliable information on sustainable energy technologies, while purchasing products based on conventional technologies is considered simple and convenient. Partly due to limited awareness, low-income consumers also tend to prefer low initial investments over low operating costs over time in their purchasing choices. [29]

Imperfect or asymmetric information. Imperfect information, which can also be categorised as a market barrier, inhibits investment in energy efficient technologies, for example when information of the performance of a technology is not made available by the provider. It is extremely common that the technology providers are more aware of the technological characteristics and performance of the products than the end users, which may produce uninformed purchasing decisions and inefficient market outcomes. [26]

Lack of trust and split incentives. Other socio-cultural and behaviour-related barriers include lack of trust between involved parties, lack of trust on the information provider, and split incentives, a situation which often occurs in landlord-tenant-relationships or other occasions where the party adopting the investment is not the same party who pays for the related expenses. Split incentives commonly hinder energy efficiency technologies that have high initial investment costs, although the technologies would often provide cost savings in the long-term due to lower lifecycle costs. [26]

2.4 Summary of the theoretical framework

Various approaches for understanding large-scale socio-technical transitions exist in literature, of which the multi-level perspective (MLP) was introduced here to provide a basis for understanding how large-scale systemic change occurs in complex socio-technical settings. The MLP is commonly used to study the dynamics of long-term transition processes, including energy transitions. It distinguishes between three levels of a socio-technical system: technological niches (micro-level), the regime consisting of predominant actors, practices and knowledge embedded in existing institutions and infrastructures (meso-level), and the broad socio-technical landscape (macro-level). Transitions occur through interactions between the three levels of the socio-technical system.

Urban energy systems were defined and their main components introduced. An urban energy system generally consists of the sectors and processes required to meet the energy service demands of an urban area, while a sustainable urban energy system also promotes socio-economic development, the health of people and ecosystems and accessible, affordable and reliable energy. Urban energy systems in emerging countries commonly struggle to meet these criteria, challenged by rapid urbanisation and a lack of institutional, human and financial capacities. Therefore, urban regions typically face challenges with the reliability of energy infrastructures and access to clean and affordable sources of energy.

The adoption of renewable energy and especially energy efficiency drive the transition to sustainable energy in cities. However, several barriers that hinder such transitions in emerging countries have been previously identified in literature. A variety of common barriers to energy efficiency and renewable energy were described and categorised into institutional and regulatory barriers, financial and economic barriers, market related barriers, technological barriers and socio-cultural barriers.

3 Methodology

This chapter describes the research methods used in the study. First, the research design and the chosen methods are presented, followed by descriptions of how the data collection and analysis processes were carried out. The limitations of the research methodology are then discussed and its reliability and validity evaluated.

3.1 Research design

This thesis studies urban energy transitions in the context of emerging markets, with the aim to identify the main urban energy challenges and barriers hindering the transition to sustainable energy in Nairobi. The study was divided in theoretical and empirical research. The theoretical research consisted of a literature review on the topics of socio-technical transitions, urban energy systems and previously identified barriers to renewable energy and energy efficiency. The theoretical framework provides a basis for understanding the studied phenomena and summarises previous research on the topic.

The empirical research was conducted as a qualitative case study, the contextual background of which is introduced in Chapter 4. A qualitative approach is necessary, when the subject of the study is a set of complex phenomena affected by socially constructed factors, for which the ability of a quantitative approach to provide holistic, in-depth explanations would be limited [30]. A case study approach was chosen, because case study is a suitable research method when exploring contemporary real-life phenomena within their specific contexts, especially when the boundaries between the studied phenomenon and its context are not clearly distinguishable. It is also a preferred research strategy when the study aims to address questions of explanatory nature. The case study involves multiple sources of evidence, the collection of which is guided by initial theoretical propositions. The data collection techniques for the case study method include, for example, interviews and direct observations. [31] The case study method was chosen for this study, as it allows the close examination of research data within its specific context.

An ethnographic strategy was also used, as the study included a field research period over an extended period of time. Ethnography involves researching the phenomenon in the specific context where it occurs. It is an approriate research strategy when the particular context and perspectives of the involved people are necessary in order to gain an understanding of the topic in a range of social settings. [32] The method was chosen for this study, as the socio-cultural context is fundamental for understanding the topic [33]. Information obtained through ethnographic methods, including direct observations in the urban settings and informal conversations with people during the field research period, allowed the establishment of a broad understanding of the studied concepts in their context. Without the additional information obtained during the field research period, understanding of the topic would have remained narrow compared to the context-dependency and numerous cultural factors involved.

3.2 Data collection

The primary data for this study was collected via semi-structured qualitative interviews consisting of open-ended questions. The initial interview question pattern was built around the research questions and further refined during the first interviews. Follow-up questions arising from the topics brought up by the respondents were asked to gain additional depth and clarification. Therefore, the specific topics discussed in interviews varied according to the backgrounds and areas of expertise of the respondents. The question pattern served more as a checklist to guide the interviews, which were rather conversational by nature.

The interviews begun with a briefing to the study and the structure of the interview. Questions of the backgrounds and roles of the interviewees were asked first, followed by the perceptions of the interviewees on the main energy-related challenges in Nairobi. They were then asked a set of questions about the barriers and hindrances for the transition to sustainable energy in Nairobi, along with their causes, consequences and suggested measures and pathways to overcome the mentioned barriers. They were also asked questions on the roles and interrelations of various actors in the energy sector and the urban energy domain. Lastly, the interviewees were given the chance to express their afterthoughts and any other questions and issues that they considered relevant for the topic.

In total 14 interviews were conducted during the period of February–April in 2018. Each interview lasted for approximately one hour and all of the interviews were conducted face-to-face in Nairobi, mostly in office settings. The interviews were recorded on audio with the permission of each interviewee and subsequently transcribed for further analysis.

The interviewees were chosen mainly through a combination of purposive and availability sampling in order to select respondents that will best enable relevant answers to the research questions [32]. Sufficient variation was ensured by selecting participants from various types of organisations and with various areas of expertise in order to achieve a heterogenous sample. To gain rich data by selecting more relevant respondents and to reduce bias in the selection of the respondents, the interviewees were also asked to suggest other people or organisations whose views and expertise could be important for the study. This sampling technique, also known as snowball sampling [32], proved to be useful especially due to the limited availability of up-to-date information found online.

The interviewed organisations and their brief descriptions are listed in Appendix A. The names and titles of the interviewees are not included, as some of the interviewees requested not to be quoted by their names. The number of interviews conducted was limited by time constraints and availability of people requested for interviews. The amount and richness of the collected data was considered adequate to reach data saturation, which is a situation where additional data collection provides little new insights [32]. Therefore, the amount and quality of collected data was considered sufficient to answer the research questions adequately in the scope of this study.

Secondary data, both qualitative and quantitative, was also collected to support and complement the analysis of the primary data. Secondary data was collected from publicly available online sources, such as industry reports, policy documents and press releases. This data was mainly used for the case description presented in Chapter 4. The secondary data alone would not have been sufficient to obtain reliable results for the study, as it proved challenging to find accurate, reliable and up-to-date information from secondary sources.

3.3 Data analysis

The primary data collected for the study was analysed iteratively in several phases. Preliminary data analysis was conducted while transcribing the interviews by making notes of initial remarks, causal relationships, repeated themes and relevant subtopics that emerged from the data.

The interview transcripts were analysed using software-assisted open coding in ATLAS.ti, which is a computer-aided qualitative data analysis software (CAQDAS). Open coding is an analysis method where qualitative data is divided into conceptual units and labelled with codes. The resulting variety of codes are then compared and placed into broader categories. [32] The transcripts were analysed in ATLAS.ti by assigning codes to relevant sentences, paragraphs or other segments of data, i.e. quotations. The codes assigned for the quotations linked them to one or several concepts and themes of the study. Comments were marked on the codes and quotes to note suggestions on the interrelations between concepts and possible linkages to theory. Irrelevant segments of data were left uncoded. The codes were finally reviewed and grouped in broader thematic categories in an iterative manner. This process resulted in a data structure of 15 categories and 73 subcategories, consisting of 658 coded quotations. The structured data was used as a basis for Chapter 5, which presents the key findings of the empirical study.

3.4 Reliability and limitations of the study

There are certain critiques commonly associated with the qualitative case study method. These include a concern of the lack of systematic procedures and the possible influence of biased views on the findings and conclusions. These can be avoided with careful research design and the systematic handling and reporting of the collected data. Second is the critique on the ability of case studies to provide ground for scientific generalisation. However, the purpose of a case study is to generalise and expand the theories to theoretical proportions and not to universal dimensions, as typically in experimental and statistical research. Another common critique is that case studies take a long time and produce an extensive amount of data, which in turn depends on the choices of the investigator, such as specific methods for data collection. [31] This was avoided by adequately limiting the scope and duration of the study and the number of interviews. Systematic handling and reporting of data was paid attention to throughout the entire process of data collection and analysis.

The reliability of qualitative data collection and analysis might be affected by participant or observer bias and error [32]. Participant bias was minimised by involving several respondents from several organisations and providing them semianonymity. Observer and interviewer biases might result from the interpretative nature of the qualitative methods used, which was paid attention to by transcribing the interviews word by word and analysing the data systematically. In order to ensure reliability and consistency in data collection, a similar protocol was used for each of the interviews and a case study database was established to store the data in an organised manner. Although observer bias cannot be fully avoided, as values and beliefs of the researcher might always affect their interpretations of the studied phenomena [32], the risk it poses to the reliability of the results can be reduced by acknowledging it throughout the research process. The use of multiple data sources or collection methods, which is called triangulation, also strengthens the validity of the study [32]. In this study, the data was triangulated by using several sources and methods for collecting data, which helps in spotting possible inconsistencies both in interviews and documents.

The study is very context specific, which limits its generalisability to other contexts. Due to the heterogeneity of the developing world, generalisations cannot straightforwardly be made to other emerging countries based on this study. However, as the initial purpose of the study was to study the specific research settings instead of producing widely generalisable results or theories, this is not necessarily a limitation. The short duration of the study in comparison to the long-term nature of the studied phenomena may be viewed as a limitation implied by the scope and duration of the research project. Also, as energy system assessments are typically conducted on a national level, comprehensive and accurate city-level data is scarce. This was also the case with Nairobi, where low availability of information, such as statistics and numerical data on both local and national levels, limited the amount of quantitative evidence to support and complement the qualitative findings.

4 Case description

This chapter gives an overview on the context of the case study, beginning with general information of Nairobi and Kenya. The beginning of the chapter sheds light on the broader context and the socio-technical landscape, including macro-level economics, politics and broad societal and environmental situations. The electricity regime in Kenya is then described in more detail based on secondary sources of information. The regime contains the established technical configurations of the energy system, such as resources and grid infrastructures, the regime actors and networks, such as utilities, and the existing policy frameworks, which guide the activities of actor groups.

4.1 Context of the case study: Nairobi, Kenya

Nairobi is a main regional hub in East Africa and a center for transport, industry, commerce and trade. The city is home to an estimated 3.7 million people, while the larger metropolitan area accommodates a population of 7.1 million. [34] The population of Kenya is estimated at 46.1 millions, of which 26% live in urban areas. The urban population of Kenya and the city of Nairobi have been growing at an annual rate of around 4%. [14, 34]

Infrastructure and urban planning have been struggling to keep up with the growth of the city, while the city government has lacked the resources to meet the needs for basic services within the area. Nairobi faces urban challenges that pose risks to the health, environment and economy in the city. The rapid unplanned growth has resulted in a large number of residents living in informal settlements, including some of the largest slums in Africa, with a majority of slum dwellers living below the poverty line. Air pollution is considered a major environmental and health issue in Nairobi, caused by vehicle emissions, industries, use of charcoal and firewood and the burning of waste in open spaces. The city also faces issues with waste management, supply of power and water, insufficient sanitation and health services and an inefficient transportation system, which causes major traffic jams in the city center. [14, 34]

Economic overview

Although still categorised as a lower-income developing country by International Monetary Fund [35], Kenya is among the most resilient economies in Africa [36]. Kenya has a GDP of 68.9 billion US$, the GDP per capita being 1 516.3 US$ [37]. Regulatory reforms have improved the business environment, with a projected GDP growth of 6.5% in 2018. Technological innovation, for example in solar PV and mobile money services, has fueled the economic growth. There is an ongoing structural transformation in the labour structure from agriculture and minerals to manufacturing and services, and Kenya aims to become an industrialised middle-income country and Africa's industrial hub by 2030. [36]

According to a report by World Economic Forum [37], the most problematic factors for business in Kenya are corruption, poor access to financing and tax rates

[36]. In Kenya, the informal sector employs approximately 75% of the country's workforce. Critical issues for Kenya's economic development include inadequate infrastructure and the high cost of energy. [38] Additionally, inflation, crime and theft, inefficient government bureaucracy, policy instability and insufficient capacity to innovate have been perceived as hindering factors for business in Kenya. World Economic Forum mentions infrastructure, human capital and technological adoption as key priority areas to foster competitiveness and economic growth in African countries [37], which are also noted by the long-term national planning strategy of the government of Kenya, Kenya Vision 2030. Kenya seeks to accelerate its economic growth through six key sectors: tourism, agriculture and livestock, wholesale and retail trade, manufacturing, business process offshoring and financial services. [38]

4.2 Energy in Kenya

Kenya has abundant resources for renewable energy, as wind, solar, geothermal and hydropower potential are widely available. Commercial energy demand is dominated by petroleum and electricity, while biomass mainly covers the energy needs of rural communities and urban lower-income dwellers [38]. In the residential sector, biomass is mostly consumed in the form of wood and charcoal for cooking and heating, but the availability of sustainable supply lacks behind of the increasing demand. Biofuels (biodiesel, bioethanol and biogas) are a potential substitute for petroleum fuels, but still used only to a small extent, partly due to the controversies between land use for biofuel production and food security. Kenya is reliant on fossil fuel imports, with petroleum accounting for 25% of the imports, although oil and gas discoveries have been made in the country in the recent years. Most of the petroleum is consumed as transportation fuels [39], and the amount of annual CO_2 emissions from fuel combustion is 14.1 Mt [24].

4.2.1 Electricity generation

In 2015, the total installed electricity generation capacity was 2 341 MW, consisting mostly of thermal (35.6%), hydro (35.1%) and geothermal (27.0%) generation capacity, whereas a majority of electricity generation consisted of geothermal (47.0%) and hydropower (38.6%). The electricity mix is shown as installed capacities in Table 1 and as electricity generated in Table 2. The term thermal is used in national documents to cover power generation from fossil-based fuels, currently mainly comprising of diesel and gas [12, 39], while additional thermal generation capacity from coal is planned. [40]

By 2021, the total generation capacity is expected to exceed 5 000 MW. Due to the variability of hydropower, the development of wind, thermal and geothermal sources to answer the increasing demand for generation capacity have been favoured [39]. Further plans to increase power generation capacity in the country are guided by the goals to diversify the generation mix, reduce the cost of power by adding least-cost generation projects, avoid overreliance on hydropower and maintain adequate capacity and reserve margins [40].

Table 1: Electricity mix by installed capacity. [40]

Source	2015/16 (MW)	% of total	2020/21 (MW)	% of total
Hydro	821	35.1	871	17
Geothermal	632	27.0	1 321	26
Thermal	833	35.6	792	16
Cogeneration	28	1.2	51	1
Solar	1	0.0	52	1
Wind	26	1.1	556	11
Coal	0	0.0	981	20
Imports	0	0.0	400	8
Total	2 341	100.0	5 024	100

Table 2: Electricity generation mix. [40]

Source	2015/16 (GWh)	% of total	2020/21 (GWh)	% of total
Hydro	3 787	38.6	2 664	20.9
Geothermal	4 608	47.0	4 134	32.4
Thermal	1 296	13.2	1 140	9.0
Cogeneration	0.3	0.003	52	0.4
Solar	0.8	0.01	4	0.03
Wind	56.7	0.58	335	2.63
Coal	0	0.0	2 593	20.4
Imports	67	0.7	1 818	14.3
Total	9 817	100.0	12 740	100

The national power generation utility, KenGen, covers 70% of the country's generation capacity (Figure 3), while IPPs account for the remaining 30%. There are several diesel-powered off-grid power stations, with plans to partially convert them to solar-diesel hybrids and add a number of solar-powered mini-grids (autonomously operated local electricity grids) to the off-grid areas. [41] While the current share of renewable energy of the total installed power generation capacity is approximately two thirds, the potential for additional renewable electricity generation in Kenya is significant especially due to the large geothermal potential, which is estimated at a total of 10 GW. [12]

4.2.2 Electricity demand

According to IEA [24], the annual electricity consumption in Kenya was 7.8 TWh in 2015, excluding losses, and electricity consumption per capita only 169 kWh. A majority of Kenya's electricity consumption is concentrated in Nairobi. According to Kenya's National Least Cost Power Development Plan (LCPDP), the Nairobi region consumes over 50% of the country's total electricity, with consistent annual increases in the electricity demand. Nairobi's peak demand was 1 241 MW in 2015, estimated to increase up to 6 745 MW by 2031. [12]

Figure 3: KenGen's on-grid power generation sites in Kenya [42].

Table 3 shows the development of electricity demand and peak load demand in Kenya until 2021, as estimated by KP [40]. The growth of Kenya's electricity demand mainly results from population growth and increased economic activity, increased electricity access and implementation of large industrial projects [41].

Table 3: Electricity demand and peak load. [40]

Year	Demand (GWh)	Peak load (MW)
2017/18	10 895	1 585
2018/19	11 478	1 750
2019/20	12 093	1 959
2020/21	12 740	2 205

The cost of power in Kenya remains high compared to the region [39]. As of August 2018, the domestic cost of electricity was 22.19 KES (Kenya Shillings) per kWh. The cost has varied between 14.13–25.57 KES in 2009–2018. Different tariffs apply for water heating applications as well as for commercial customers, which are classified into six tariff groups based on their demand, with the tariffs further divided into peak and off-peak charges. Additionally, several variable surcharges apply, most of which are announced monthly by KP. The surcharges include fuel cost charge based on the cost of thermal power generation in the previous month, inflation and foreign exchange adjustment rates and various taxes and levies. [43, 44]

4.2.3 Electricity distribution and transmission

The government of Kenya targets to achieve universal electricity access in the country by 2020. Access to electricity has increased significantly due to the extensive national electrification efforts of KP and REA, growing from 26% of households to 46%

between 2011–2015. The expected population with access to on-grid electricity has recently been estimated at 70–80%, in contrast to less than 50% in 2015, while the remaining 20–30% may be expected to receive off-grid access to electricity. [41] KP aims to reach its strategic objectives of improving supply of quality, reducing technical losses and expanding the network by automating existing and new networks, modernising power generation and increasing the number of connections through various infrastructure development initiatives [40].

The distribution and transmission system is highly unreliable and inefficient with frequent power cuts and high distribution and transmission losses, estimated at 19.4%, while KP targets to reduce losses below 10% by 2021 [40]. Several measures have been undertaken to strengthen and extend the distribution network, but despite the national electrification efforts, the development of the quality and coverage of the grid has been hindered by factors such as the required large investments [39, 45]. The maintenance of the network has improved with the increased employment of digital technologies and geographic information by the national electricity utility [36], with other improvements such as streamlined online approval processes to simplify accessing electricity in terms of administrative procedures and processing time. Significant increases in the transmission network are underway and planned in Kenya (Figure 4), in addition to regional interconnections to Ethiopia, Uganda and Tanzania [41].

4.2.4 Key institutions in the energy sector

Kenya's energy sector is generally highly controlled by the public sector, although the national utilities have been partially privatised. State-owned utilities operating under the **Ministry of Energy (MoE)** are mostly in charge of the generation, transmission and distribution of electricity in Kenya. **Kenya Power (KP)**, previously Kenya Power and Lighting Company (KPLC), is a 51% government-owned monopoly responsible for electricity distribution in Kenya. **Kenya Electricity Generation company (KenGen)** is the national electricity generation company, which covers a majority of installed on-grid electricity generation capacity and is 70% state-owned. **Kenya Electricity Transmission Company (KETRACO)** is a fully state-owned company responsible for the national transmission grid and regional interconnections. **Energy Regulatory Commission (ERC)** is a separate body in charge of regulation in the energy sector and preparation of the LCPDPs. The government also hosts agencies that are in charge of major electrification and development programmes. **Rural Electrification Authority (REA)** is responsible for the implementation of the national rural electrification programme together with the national electricity utility. [47]

Additionally, Geothermal Development Company is in charge of the development of the geothermal sector and Kenya Nuclear Electricity Board manages the development of nuclear electricity sector. The State Department of Energy hosts directorates for electrical power, renewable energy and geo-exploration. The aim of the renewable energy directorate is to promote the development and use of renewable energy from biomass (biodiesel, bio-ethanol, charcoal, fuel wood), solar, wind, tidal

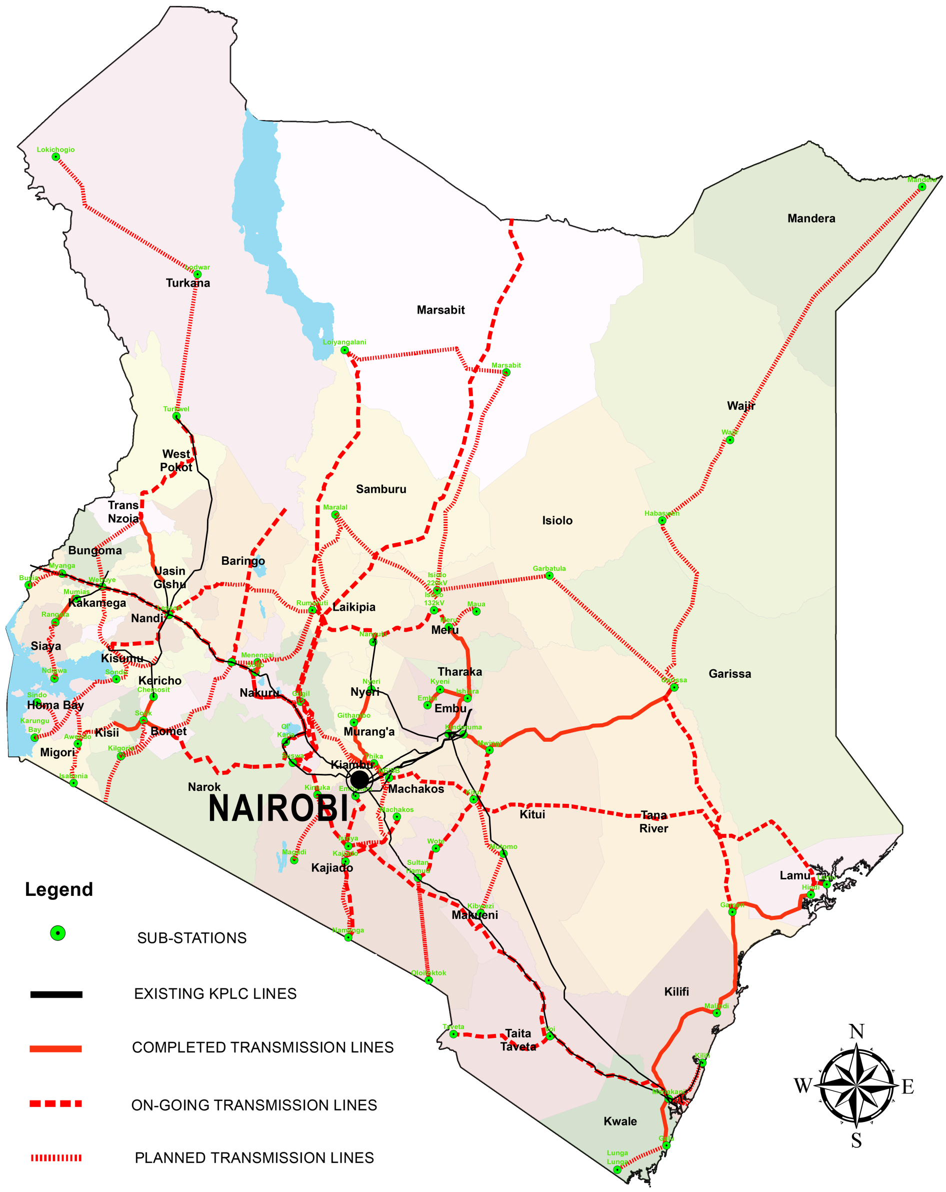

Figure 4: Kenya's national transmission grid, including planned transmission lines and lines under construction. Modified from [46].

waves, small hydropower, biogas and municipal waste. In addition to the government organisations under the Ministry of Energy, private investors in the power generation sector, addressed as independent power producers (IPPs), generate and sell electricity under power purchase agreements (PPAs) with Kenya Power, the national electricity utility. [47]

4.2.5 Regulatory and policy frameworks

Kenya Vision 2030 is the blueprint for the development of the country for the period of 2008–2030, which aims to "transform Kenya into a newly industrialising, middle-income country providing a high quality life to all its citizens by the year 2030". Vision 2030 is based on three pillars: the economic, the social and the political, aiming to improve economic prosperity, social equity and political democracy in Kenya. The blueprint mentions high energy costs and increasing demand as the main energy-related development challenges, calling for solutions to increase power generation and energy efficiency while lowering related costs. The government states its commitment to continuous institutional reforms, which include strong regulatory frameworks, encouraged private sector power generation and separating generation from distribution. Further generation capacity is expected to be added through geothermal power, coal and renewable sources, as well as improved regional integration between Kenya and neighboring countries. [38]

Kenya's long-term energy sector planning is guided by the **Least Cost Power Development Plan**, which defines how Kenya is going to meet the growing energy needs with least costs to the economy and the environment [12]. The **Last Mile Connectivity** is a government-driven project to increase electricity access in the country and achieve universal access by 2020 [41]. Kenya has adopted several policies and regulations targeted at encouraging renewable energy, including the **Feed-in-Tariff (FiT)** policy, **zero-rated import duty and removed value-added-tax** for imported solar PV, solar water heating (SWH) and wind power equipment as well as specific regulations for solar PV systems. Clean and renewable energy technologies are also encouraged in the **National Climate Change Response Strategy** and the **Climate Change Action Plan**, which are national plans for climate change mitigation and adaptation in Kenya. [48] Additionally, the **Solar Water Heating Regulation** introduced in 2012 requires all premises with a hot water consumption of over a hundred litres per day to install and use solar heating systems [49].

Advancements in Kenya's policy and regulatory environment in the electricity sector include the unbundling and partial privatisation of national utilities and an increasing presence of IPPs. [41] President Uhuru Kenyatta has publicly encouraged both local and foreign investors to engage in green energy projects in Kenya, as a wide range of reforms by the government have taken place to improve the possibility of private sector participation in economically viable energy provision projects [50]. Investments in Kenya's electricity sector have been reliant on financing from development partners and development finance institutions. Commercial investments in the electricity sector have significantly increased, although there are still several hindrances, such as a challenging financing environment for commercial capital, lack of constistency and transparency in the processes for securing financing and insufficient financing mechanisms. [41] The development of the renewable energy sector has also been challenged by the high initial costs, low awareness of potential opportunities and benefits and the suppliers' unconcern of compliance with system standards. Companies are perceived to face challenges with limited access to technological information as well as legal and regulatory barriers. Various licenses and clearances required for initiating renewable energy projects have also been poorly informed. [51]

At the local level, policy documents targeted at urban development in Nairobi include the **Nairobi Urban Development Master Plan**, published in 2014, and the **New Urban Agenda**, published in 2017, which also include measures and recommendations in regard to energy and electricity on a broad level. The Urban Development Master Plan, developed by the county government with technical assistance from Japan International Cooperation Agency, briefly mentions the solar water heating regulation, the gas distribution networks and broad suggestions, such as "appropriate planning for the energy sector", including recommendations to consider renewable energy and review some of the current plans and policies, such as the least cost power development plan. [34] The New Urban Agenda, based on UN recommendations and published by Kenya's Ministry of Transport, Infrastructure, Housing and Urban Development, mostly addresses issues related to housing, land use and urban governance. It also includes declarations of Kenya's commitment to sustainable urban development, including the commitment to "the generation and sustainable use of renewable and affordable energy by promoting energy efficiency and conservation to reduce greenhouse gas and carbon emissions and ensure sustainable consumption and production measures", energy efficient buildings and construction with sustainable materials and the adoption of a "smart city approach", which also includes clean energy technologies. [52]

5 Empirical findings

This chapter presents the findings of the study by describing the main themes that emerged from the empirical data. Quotes and examples are used to illustrate the discussed topics.

5.1 Reliability of supply

A majority of the interviewees mentioned the unreliability and inefficiency of the electricity grid as the largest electricity related challenge in Nairobi. Power outages and power quality problems are common, and a lot of power is lost through transmission and distribution losses due to the inefficient, overburdened and aging distribution infrastructure. Blackouts occur especially during heavy rains and can last for several hours. There was no power quality data available to provide any numerical information on the actual frequency and duration of blackouts and other power quality problems.

A representative of the national utility agreed that reliability of supply is an issue and becoming more problematic especially with the growing demand for electricity. The unplanned incremental growth is straining the power system, with line extensions and overloaded transformers resulting in voltage drops and blackouts. Because the growth is rapid and difficult to predict and plan, structured and systematic approaches to reinforcing the power system become challenging.

Quality of supply is a challenge especially for industrial users with manufacturing processes that require a steady supply of energy. Power outages and other disturbances in the grid hinder productivity in the industrial and commercial sectors, causing disruptions in manufacturing processes and other commercial activities, as stated by one of the interviewees:

> *"Reliability of electricity supply. That's one of the main points from a macro-economic point of view, because half the GDP is generated by Nairobi. Whenever there's a power cut, the losses are huge."*

Industrial and commercial players have encountered the reliability issue by acquiring their own backup power systems. Although there is increasing interest towards solar and battery based backup power systems, mainly diesel generators are currently used to provide power during blackouts and to ensure steady supply of power to critical functions. Generators are also common in residential buildings, although a majority of households cannot afford them. Some have acquired solar lanterns to provide lighting during blackouts or appliances that have a built-in battery to reduce their dependency on the unstable grid power.

Diesel generators are among the main contributors to the air quality problems in Nairobi, in addition to road traffic. Pollution is a major challenge and a health hazard in the densely populated city. The more power outages occur, the more diesel is being used. The cost of diesel is also increasing, which is becoming expensive, while the high and volatile cost of power is already a challenge.

Although the grid is still highly unreliable, some of the interviewees mentioned that there has been a clear improvement in the quality and consistency of supply in the recent years. Several respondents commended the utility on its recent efforts on improved reliability and reduced power outages, as earlier there used to be power outages "pretty much every day". One interviewee described that a decade ago the blackouts were daily, because the utility had to constantly switch off areas due to an insufficient energy supply, while the economy was growing rapidly. Generation capacity was no longer considered an issue, since there is now surplus capacity, but the distribution infrastructure is still vulnerable to e.g. weather conditions:

> *"Things have really improved in the last five years. I rarely get blackouts, unless it's raining. If it rains, you're 100 per cent sure there is going to be a blackout."*

There has been several measures targeted for improving the reliability of the electricity grid. The utility has introduced regional managers, each of whom is in charge of a certain region, which is why problems can now be addressed with less delay than before. The outages caused by planned service and maintenance breaks are nowadays communicated in advance, which was not the case before. In the industrial areas, the distribution infrastructure has also been strengthened by underground cabling and increased substation capacity. A respondent from a research organisation commended the Kenyan utility on its efforts and performance on improving the reliability and efficiency of the grid, as although there is room for improvement, the situation is significantly better compared to many other countries in SSA.

The utility has also been piloting smart meters, which can be used to monitor blackouts in real-time instead of waiting users to call and report the issues, and installing monitoring systems to recognise faulty transformers. These are small steps towards a more proactive approach on grid improvement and maintenance, although supply issues are still mostly addressed in a reactive rather than proactive manner. Several respondents thought that the utility should allocate more resources on operations and maintenance, as simply trimming trees along the power line routes would make a notable difference.

> *"Smart grid is in the distant future. Right now we just need like poles not to fall, some of them are very old. Trees next to power lines and those basic issues..."*

> *"Very simple things. Just look at the lines and you see branches on the lines, one of the branches breaks off and you get a power cut... They should do more on operations and maintenance."*

Another interviewee explained that as most of the utility's profits come from a relatively small number of customers, mainly industries and other large users, KP does not have sufficient incentives for improving the infrastructure, since it would not increase their profits. Therefore, it was suggested that the utility should be regulated through e.g. penalties for power quality problems. More private sector involvement in the electricity sector was also hoped for, as there was a perception that private sector players are more efficient and trustworthy than the public sector.

Whereas stand-alone solar PV systems and mini-grids have significant potential in powering the rural off-grid areas of Kenya, most of the interviewees agreed that Nairobi will stay dependent on the electricity grid. As the grid infrastructure already exists and the connectivity levels are high, the relevance of mini-grids and solar home systems for the capital area was considered low. There are a number of private utilities implementing mini-grid projects in the rural areas, but they were not seen to enter the urban areas, where the grid infrastructure already exists.

Solar PV and battery electricity storage systems were seen as a better alternative for the widely used diesel generators, but the interviewees predicted that the utility will likely be able to improve the reliability of the grid before solar and battery systems could become a widely adopted source of backup power. The question is mainly of affordability, as grid electricity is significantly cheaper than such systems.

Three different interviewees estimated the transmission and distribution losses at approximately 20%, which is a large share of all power fed into the grid. As one interviewee pointed out, it is "a lot, about 100 MW of electricity… bigger than the largest power plant in the country". There was a clear consensus among interviewees that while generation is no more among the main energy challenges, distribution is.

5.2 Access to electricity

On a national level, access is still the main concern regarding electricity. The interviewees often compared Nairobi to the rural areas, mentioning that although there are issues with reliability and affordability of energy, Nairobi is still "better off", because at least it is covered by the national grid, while rural areas face different challenges. Therefore, electricity access is still clearly and justly the priority on a national level. The interviewees believed that the government is focusing on the target of achieving universal electricity access prior to addressing the efficiency and reliability of the transmission and distribution infrastructure:

> *"In Africa, immediate focus is on access. Everybody is looking at providing access for the 600 million people without access, that is the first priority."*

> *"First point of discussion is always access. Once access is there, then."*

The estimates on connection rates that can be found online vary greatly, but according to a utility representative, the electricity access rate in the whole country is around 72% of the population. Connectivity level in Nairobi was estimated at 80–90% by several respondents.

Connectivity in Kenya has improved significantly in the past years along the establishment of the REA and the Last Mile connectivity project. A number of the new connections were also in urban areas. According to one of the interviewed researchers, government-driven rural electrification programmes have managed to connect more people in the past five years than had been connected since Kenya's independence. Another interviewee commented:

"KP has been able to connect from just 2 million in 2012 to over 6 million connections now. It's quite incredible. Of course, people ask if it's really 6 million or are they just putting up numbers, but it's very high, should be around that number."

A representative of the utility highlighted the importance of development funding in having enabled the improved connectivity due to the heavy investments required by power infrastructure projects:

"These are long-term loans, maybe you can expect that the returns might come 30–40 years down the road. For a commercial entity like KP, there is no immediate motivation, because there are basically no returns. It's more of an increase in transmission and distribution costs than an investment."

The electrification programmes, financially supported by several development partners, have offered connections at lowered costs, having enabled electricity access for a number of low-income households that were not able to afford connectivity before. Most of the new connections are for domestic users, who are mainly low-income earners with little more electricity needs than lighting and charging phones. Due to this, the returns per customer reduce as more people are connected, which becomes economically challenging for the utility, which is responsible for maintaining the distribution infrastructure. According to the utility representative, transmission and distribution costs are increasing with the amount of connected users, while revenue growth is on a plateau. Therefore, the utility is not well motivated, and the grid extension has been more of a government-driven project.

An interviewee from an energy consultancy commented that the pressure of connecting large numbers of customers without the resources for maintaining the extended grid places the utility in a difficult situation:

"Millions of households paying KP 3–5 dollars a month and all of them calling KP when they have a blackout, that threatens the sustainability of KP... In any other service, when customers increase, at least revenues increase... Government wants everyone on the grid, but resources also need to be allocated to know that it's done well."

There were suggestions that instead of extending to the off-grid areas, the utility should focus on improving the existing grid, leaving the off-grid areas to mini-grid companies and other private sector players. A utility representative also thought that instead of extending the grid, mini-grids and decentralised renewable production should, for now, power the areas that are not reached by the national grid. There has already been significant increase in the uptake of off-grid solar PV systems in these areas, partly driven by a push from various development agencies and international companies.

The national-level pressure to power the rural areas of Kenya was seen as a key reason for the absence of sufficient discussion on urban energy issues, which might change in the near future, as the population of the country is rapidly urbanising. One researcher highlighted that the urban economy is very important for Kenya, which is no longer primarily a rural country:

> *"Focus is primarily on renewable production and rural energy and not necessarily on urban energy, which is a thing on oversight, because the urban economy now in Kenya is very important and the population is becoming increasingly urbanised."*

5.3 Affordability of electricity

Providing reliable, clean and affordable energy for low-income users is a persistent challenge throughout SSA, also in Kenya. A majority of low-income households and small-scale businesses lack the ability to purchase clean and reliable energy. Some interviewees emphasized that energy poverty is one of the most pressing challenges in the area:

> *"In my opinion, the biggest challenge to energy... is hands down poverty. Lack of modern energy is primarily a poverty question. People talk about policy, investment climate, access to financing, capacity, technology and all these things, but all those are secondary. People cannot afford modern energy in Kenya and many African countries."*

Sustainable cooking fuels and technologies, like improved cookstoves, biomass-based cooking fuels, briquettes, liquid petroleum gas (LPG) or electricity, not to mention solar PV systems, are simply more expensive than kerosene, which is easily available and relatively cheap, but also a pollutant and a health hazard. Kerosene is widely used for cooking and lighting in low-income households.

> *"Low-income households spend a very disproportionate amount of their income for energy. Some have to make a choice between cooking and the food they purchase on a daily basis."*

It is also a question of awareness, as the low-income communities are often not aware of the available options to reduce their energy-related costs. Although some of the cleaner forms of energy or more energy efficient appliances could become more affordable in the long term, the higher upfront costs usually prevent people from purchasing them.

> *"If you tell someone to change to energy efficient bulbs... When they go and see the price, they are like no, because for them, energy efficiency [etc] are fancy words that academics and very educated people use, climate change too. So you have to speak in money, because money is what makes sense especially to someone in a slum."*

It is often not possible to provide safe connections for informal settlements due to "fire and electrocution risks". This lack of proper infrastructure and housing is another reason why large areas in slums have lacked electricity connections, and therefore illegal connections have been another issue in Nairobi. It is not uncommon that slum dwellers tap power from the overhead lines, which is both illegal and dangerous.

An interviewee, who had done research on energy provision for the urban poor, commended the utility for its innovative work on improving electricity access and reducing illegal connections in slum areas with the involvement of the local communities. The initiative, supported by the Global Partnership on Output-Based Aid under the World Bank, has provided slums and other low-income areas with meter boards and a lowered cost of connection, which has helped answering the basic electricity needs of slum dwellers, who primarily need electricity for lighting and charging phones. Another interviewee commented that the program has been very successful in terms of increased connections, although the cost of electricity is still too high for many to afford, as an "equivalent of 25% of your rent goes to paying for electricity".

There were also concerns about the rapid growth of the urban population, as many people move to Nairobi from elsewhere in Kenya to look for jobs. Especially the informal areas are expanding rapidly, as people often first move into the slums until they get a job and another place to stay, but as one interviewee put it, the slums are "like a holding area before you can make it. . . but many people end up staying there for 10 or 20 years".

5.3.1 Cost of power

The cost of electricity has been volatile in Kenya, partly due to the seasonal droughts. Many people mentioned that the droughts had been getting worse in the recent years, supposedly due to climate change. During the droughts, fossil-based power plants have to be employed to make up for the high share of hydropower in the generation mix. The high costs of imported coal, diesel and other fossil fuels are then reflected in electricity prices.

> *"Regards to generation, climate change plays a significant role. Kenya has been reliant on hydropower for the generation, now there is not too much water, especially during droughts. When it's raining, it's fine, but when it stops raining, you get a problem. Price goes high, electricity cost goes high, because you have to use thermal, that's one challenge. I think that could be the main one. . . "*

The costs were estimated to further increase due to the large investments required in the electricity grid in the near future, as the peak and overall demands are on the increase, while the reliability and accessibility issues require continued attention.

> *"The main challenge is the cost of grid electricity, as the projection is that it's going to keep going up. Nairobi has very few choices, so the cost of electricity will continue to go up."*

Interviewees also lamented the unclear formation of the cost of power, as no one seems to know what their power bills consist of, what the price of power is going to be or where the money actually goes to:

> *"There's been complaints that KP has been inflating their bills, just adding like 20% on everybody. I don't know whether it's true or not, don't have the data or evidence. That could be because of many things. We had a drought for long time, so hydro goes down and they use more diesel, that could be a factor... I'm sure they are under a serious financial strain."*

> *"Electricity is too expensive. The rate we pay as domestic users is around 30 shillings and it's been going up... Our utility company has really been doing acrobatics on the power bills... Cost of electricity is a big discussion, a hot potato in Nairobi currently."*

Two of the interviewees also mentioned that in addition to the inefficiencies, the fact that the utility is virtually a monopoly prevents the costs from going down.

> *"It fluctuates very much, you can't really predict. Especially when they start including non-renewable energy... Kenya has one of the highest costs of energy... because at the moment KP is a monopoly, the utility company. If they choose, you don't have the option."*

The interviewees also thought that running the costly thermal plants does not make sense, when the country has abundant potential for cost-efficient geothermal power generation, which could remove the need for fossil-based thermal power generation. Another option to lower the costs, according to one interviewee, would be a higher share of solar PV in the generation mix:

> *"Solar is really, really cheap now in terms of generation, or a balance between hydro and solar would work very well, because during the dry season there is a lot of sun. Equivalent [solar] power plant for every hydro power plant would mean that during the day they close the [hydropower] plants and use the solar, and then they use the dam as a battery. At night, they discharge from the dam based on the demand. If they did that, their cost of generating power would be significantly lower."*

5.4 Electricity generation

A major share of Kenya's electricity is generated from renewable sources, mainly geothermal and hydropower. Additionally, thermal generation is used, especially when hydropower is low. There is increasing interest towards solar and wind, which currently cover a relatively small share of total electricity generation.

Kenya has more generation capacity than demand. The interviewees explained that this is because renewable energy projects in Africa attract funding, but there are not as many projects on the demand side, such as manufacturing. Some also thought that because of improved energy efficiency, the growth of demand has not been as high as predicted. Another explanation for the excess generation capacity was political interests. There has been discussion of a more integrated power system between several East African countries, which would allow Kenya to export the excess supply to neighbouring countries.

5.4.1 Solar PV

Solar PV is seen as a promising enabler of rural electrification in Africa, but the relevance of distributed solar PV generation for urban areas is not as distinct. The interviewees had differing opinions on the potential of solar PV generation in the urban areas of Kenya.

The high upfront costs were seen as the main hindrance for solar PV systems, both on-grid and off-grid. The relevance of off-grid systems in the urban areas was considered to remain low, as grid electricity will remain the cheaper option and the connectivity level is high. The economical feasibility of on-grid systems is likely to improve with the new Energy Bill, which includes regulations on net metering. However, selling excess electricity to the grid is not possible for smaller individual customers, as the minimum threshold for on-grid solar PV systems to acquire a PPA is 500 kW.

Several interviewees mentioned that industrial and commercial facilities are increasingly adopting solar PV generation. Drivers for the increasing interest include the issues of grid reliability and the high and unstable cost of grid electricity. One interviewee thought that also the improved availability of financing targeted for such systems has made the companies see the economic benefits of generating their own electricity and becoming IPPs. Additionally, solar PV projects attract international investment.

Many believed that Nairobi will rely on the distribution grid and centralised generation, as the infrastructure is already in place, and that solar PV could basically be used as backup systems. However, a few interviewees saw that especially in the long-term, decentralised generation and mini-grid or community level infrastructures could become common. This was also the point of view of a utility representative, who saw the field of decentralised electricity generation and distribution more as a collaboration opportunity than competition:

> *"It will be better to accept that decentralised generation is the way of the future. Then we see how to leverage them and regulate them as a utility. . . so that they also become a part of our network and systems through collaboration and partnerships."*

One interviewee believed that in the next 5 to 10 years, most new buildings will have rooftop PV and SWH systems. A challenge with wider solar PV generation is that the power is generated during the day, when the demand is low, while the demand peaks in the evening when there is no daylight.

5.4.2 Other renewables

There is one wind power plant located in Ngong (25.5 MW), right outside Nairobi. Otherwise there is little potential for wind generation close to the city. A large wind power plant (330 MW) was recently built in Turkana, in northwest Kenya. The plant is completed, but it has been on standby due to delays in building the transmission line. While the Turkana plant is still offline, the Ngong plant is the only grid-connected wind power generation site in Kenya.

Hydropower covers a large, although varying, share of Kenya's electricity generation. Overreliance on hydropower had been an issue, because during the drought seasons, thermal generation has to be brought up, which also increases the cost of electricity.

Geothermal energy was considered an abundant, stable and cheap source of electricity in Kenya, although not in the vicinity of Nairobi. There is plenty of local expertise and experience of geothermal energy in the country. A few interviewees also saw geothermal as a potential way to reduce and stabilise the cost of electricity and cut down thermal generation.

5.4.3 Waste-to-energy

In addition to solar PV, waste-to-energy (W2E) was seen as a potential way to increase local power generation in Nairobi. The interviewees had heard of several plans and initiatives for establishing a W2E generation facility within the city, but apart from one existing small-scale pilot site, no one was sure whether one was going to be implemented for the time being.

There are no W2E plants in operation in Kenya yet. There were favourable opinions and substantial interest towards W2E, as it could also be helpful in addressing the waste management issues in Nairobi. According to one interviewee, a US-based company was looking into establishing a plant in Nairobi, but withdrew from the project due to insufficient feed-in-tariffs for the project to be economically feasible.

5.4.4 Fossil fuels

Kenya imports fossil-based fuels, such as diesel and LPG. A relatively small share of Kenya's electricity is generated from fossil fuels, but during droughts, the share of thermal generation from fossil fuels is higher to make up for the lower availability of hydropower. Diesel generators are also widely used to provide backup power locally during blackouts. In addition to electricity generation, fossil-based fuels are used as transportation and cooking fuels.

The consensus among interviewees was that fossil fuels should be cut off from the electricity generation mix. According to the interviewees, the imported fuels are reflected in high electricity prices. Most of the thermal power capacity is idling, and the rest could be shut down after Turkana wind power plant comes online. However, the government has plans to build a coal power plant in the coastal town of Lamu, driven by Chinese investment, which the interviewees generally thought makes "no sense at all", especially when there is idle capacity at Turkana wind power plant and vast geothermal resources in the country. The interviewees thought that coal power is polluting and unnecessary, and it would further increase the cost of electricity due to the imported fuels. They did not see any apparent reason for building the coal plant other than "political interest", and whether the plant will actually be built "remains to be seen".

5.5 Electricity demand

More than a half of all electricity generated in Kenya is consumed in Nairobi, as a large share of population and the country's economic activities are concentrated in the capital area. Peak loads are an issue for the reliability and efficiency of the grid.

Improved energy efficiency, both in urban households and industry, was considered the best way to reduce the peak demands. At the industrial and commercial sectors, several possibilities exist for energy efficiency improvements. The energy audit requirement was seen as the most significant recent development in industrial energy efficiency. Net metering and smart grid solutions were also brought up by the interviewees as means to control the peak loads.

According to estimations based on the government's vision of Kenya as a middle-income country, the electricity demand will grow roughly tenfold by the year 2030. A couple of interviewees thought that while a tenfold growth in twelve years sounds like an enormous increase, it is a very probable scenario. There were different opinions on how significantly the increase in the urban population and their electricity consumption will drive the growth of demand, and how much of an issue the growing demand in the urban areas is likely to be:

> *"I think the distribution and supply of electricity is going to grow, so that's not a problem."*

> *"Rapid growth of the city is really creating enormous problems across all these energy options."*

Kenya has a least-cost development plan for power projects to meet the growing demand. Some interviewees were still worried that the increased capacity will also increase the already high cost of electricity, as people will "have to pay for whatever is being generated".

The increasing demand due to the rapid and uncontrollable growth of Nairobi also complicates the planning of urban areas and their infrastructure:

> *"The growth is phenomenal, you can also see it in like traffic, water and sewage systems. The city is bursting at the seams... it's a big issue. Actually I sort of dread the future, how it will play out in Nairobi. Because I think we are getting to where the city will not hold. It cannot be one city anymore, just because of the rapid growth."*

> *"Challenge is that Nairobi is growing rapidly. 6–8% annual growth, population doubling every 10–20 years. That's insane, how do you plan for that?... If the population was steady, or a manageable growth of 1–2%, it would still be a challenge to move everybody to cleaner, more sustainable forms of energy."*

Nairobi was considered a potential ground for a number of energy efficiency improvements. Demand side management and energy efficiency were deemed the "first things that Nairobi would have as a top priority for a sustainable energy future", because "it is local, doesn't require a lot of capital and can be scaled up".

One respondent also believed that electricity storage systems, such as lithium-ion battery storages, have "immense potential" in both reducing the dependency on the unreliable grid as well as evening out the demand peaks, which could also improve the reliability of supply. They suggested that utilities and large companies could set up storage facilities in different areas of the city to strengthen the supply of electricity.

In terms of energy efficiency in buildings, Nairobi has an optimal climate, as neither heating or cooling are necessary. Switching to energy efficient lighting was considered as the most potential single measure that can affect the energy efficiency of buildings. A representative of the Kenya Green Building Society (KGBS) thought that the aspects of energy and sustainability are still not sufficiently taken into account in designing the built environment in terms of materials and use of natural lighting. The Green Star rating has been adopted for use in Kenya to answer the previous lack of locally applicable and modern building standards. In addition to energy, the rating includes the aspects of materials, environment, health and accessibility. An interviewee from an energy industry association commended KGBS on facilitating the development of the standard, which is now "a locally accepted standard for urban planning".

5.6 Policy and regulation

The regulatory and policy frameworks were mentioned as the main drivers for the sustainable energy transition in Kenya. Substantial improvements have taken place in the policy environment, which the interviewees thought is currently "good", "quite straightforward" and with "no major barriers". People had positive thoughts about the work of the Energy Regulatory Commission (ERC), which "has been able to bring regulations that are able to help in adopting energy efficiency and renewable energy in the country". These policies include regulations on energy management, solar PV and solar water heating as well as feed-in-tariffs and tax exemptions on solar products. As two association representatives phrased it:

> *"I can proudly say Kenya is way ahead in the region, energy efficiency and policy structure. That is the work of ERC."*

> *"I think the efforts really come from the ERC... We have SHW regulation, solar PV regulation, energy management regulation. The regulator has done a lot in terms of creating awareness and enforcing these regulations, which has created an uptake in renewable energy and energy efficiency awareness."*

The interviewees also thought that lobbying for renewable energy and energy efficiency has been among the main drivers for the policy improvements. Industry associations, such as Kenya Renewable Energy Association (KEREA) and Association of Energy Professionals East Africa (AEPEA), have participated in assisting the government with the formation of the energy policies, such as the net metering regulation of the new Energy Bill.

There are no local energy policies in place at the level of Nairobi county. Some interviewees thought that there is misalignment between the county and national governments in terms of policy development, and that the county government does not have sufficient capacity or incentives to develop adequate county level energy policies and plans.

5.6.1 Solar water heating

The interviewees commended the recent regulation on SWH, which requires buildings with a warm water consumption of over 100 litres per day to install solar water heating systems. New buildings are no more approved without a design for SWH included in the plan, and existing buildings are increasingly adopting the SWH systems.

One consultant doubted whether the regulation is actually implemented in practice, as owners of buildings might not have sufficient incentives to install the costly systems. However, an interviewee from a company installing energy systems told that since the regulation came into effect, their business had mainly consisted of installing SWH systems. Another interviewee had also noticed a "quick uptake" of SWH systems among both domestic and industrial customers. Several agreed that the SWH regulation is among the most important recent energy efficiency developments in Nairobi. There were also suggestions that more could be done with the energy efficiency in buildings, by e.g. improving the regulatory frameworks concerning building standards and better integration of energy efficiency in the built environment.

5.6.2 Energy Bill and net metering

The new Energy Bill has been on hold since 2015, waiting for approval of the parliament. It includes regulatory measures that would further improve the policy framework concerning energy efficiency and renewable energy. The interviewees were especially waiting for the policy on net metering, which would enable consumers to act as prosumers, generating their own electricity and selling the excess back to the grid. Net metering would therefore significantly improve the economical feasibility of grid-connected solar PV systems. The minimum threshold for systems allowed to sell electricity back to the grid is currently 500 kW.

There were several explanations for the delayed approval of the Energy Bill, most common of which was that it would affect the profits of the grid owners, i.e. the utility. An interviewee from a financing institution thought that the Energy Bill is delayed because of resistance from the profit-oriented utility. Another interviewee agreed, saying that the utility is against net metering "for obvious reasons, because they would lose their very big market share".

However, a utility representative thought that net metering would be necessary in order to encourage decentralised renewable electricity generation within the city. They saw that increased decentralised power generation would be a good thing for the utility, as it would reduce the need to import power from outside the city, which is "becoming more expensive". They suggested that combined with grid electricity storages, rooftop solar PV could also help to reduce demand peaks, which are straining the distribution grid.

Another interviewee thought that the introduction of the new Energy Bill will remove the remaining barriers concerning the policy frameworks. Two of the interviewees pointed out that the policies and regulations that will be introduced in the Energy Bill will also drive power infrastructure improvements, as the utility will have incentives to minimise power quality issues and grid losses.

5.6.3 Feed-in-tariffs and tax exemptions

A few interviewees mentioned that the Feed-in-Tariff (FiT) policy has played a big role in promoting renewable power generation, while the tax exemptions on solar PV and SWH systems encourage the adoption of small-scale renewable energy technologies.

An interviewee from an energy industry association thought that such rebates are a good incentive for implementing capital intensive energy projects. There were also critical views on whether the feed-in-tariffs are sufficient to make power generation projects feasible enough, and whether the tax exemptions actually work in practice or only on paper, as the process of getting the tax reductions had been considered cumbersome.

5.6.4 Energy audits

Another significant energy efficiency policy is the energy audit requirement for industrial facilities and large companies, for which the implementation efforts of KAM were commended for by a couple of interviewees. Some doubted whether the measures and improvements identified in energy audits are actually implemented by the audited facilities and whether all the facilities concerned by the requirement are aware of it.

5.7 Awareness and availability of information

Many interviewees mentioned lack of awareness among the main hindrances in the sustainable energy domain. The topic of awareness was brought up in various contexts, and it was discussed in relation to awareness of technologies and their various benefits, quality issues, existing policies and regulations, financing options and sustainability issues. Lack of awareness was seen as a wide issue among the general public, users of various technologies, decisionmakers as well as companies in the energy sector.

> *"Awareness is very low. We need to do a lot of awareness creation, primarily on the end user."*

> *"Energy efficiency... the issue of training, creating awareness on even how to use energy in the first place... because the skills are not there... Awareness and usage are as important as the connections themselves."*

Public awareness was considered to be better in Nairobi than in the rural areas, where the population is not as dense and where there might not be means of modern communication. In Nairobi and other urban areas, smartphones and internet connections are increasingly common, which has improved access to information for a large share of the population.

Still, there is "very little public education, especially for the low-income communities". Awareness creation was considered difficult, requiring long-term commitment and consistency, while many awareness programs only run for a short duration of time.

> *"Once in a while they run a program, but it's not continuous. Awareness programs is like advertisement, you just have to stay at it... Constantly running, reminding people, showing the costs, explaining it in different ways."*

> *"Utility has also been in the forefront in enlightening consumers on energy conservation... adverts on television on how to conserve energy, how to install efficient appliances in your houses... "*

There were also doubts on how widely the existing regulations and policies are actually being implemented or complied to, simply because the people they would concern are not aware of them. Examples included the SWH regulation and the regulations that are supposed to encourage the adoption of solar PV systems:

> *"[Solar water heating] is being regulated already. But it's not being implemented, because people don't know about it."*

> *"Solar PV supposed to be zero duty rated, no one's done that. People find it's so difficult, they're like I'll just pay for the tax, I just want the solar PV on my house by next week. Otherwise it takes so long it demotivates people... Even importers don't know about it when they import solar PV... That awareness and communication thing is very bad."*

Three different interviewees mentioned that Nairobians are very eager to adopt new technologies. One also added, that everything "starts here and then spreads to the rest of the country". Several interviewees agreed that awareness creation through the sustainability terminology will not affect a large majority of population, who earn low incomes and therefore have very different priorities than climate change and sustainable energy. Instead, the benefits of e.g. energy efficiency and energy conservation should be communicated through the cost savings that they can bring, as "everyone in the world understands money":

> *"Quantified in terms of dollars or shillings, that's the language most people understand... The uptake of sustainable and renewable energy and energy efficiency, a language that they don't understand."*

Some interviewees had also noticed an increased awareness and concern of sustainability and climate change, which they thought now seemed to be high on the agendas of governments and businesses. One interviewee told that the government is requesting all their new buildings and developments to be "green".

> *"Climate change is at the forefront of everybody's thinking now and seems to be quite real... on everybody's agenda."*

> *"We've now talked about sustainability and the issues of future... there's now a lot of environmental consciousness."*

The awareness question is also closely related to the availability of information and the access to it. The information that is available is often outdated, comes from unreliable sources or is otherwise inaccurate. The poor availability of information, data and statistics was also said to hinder planning and policymaking in the sector, as there are no basic statistics available on, for instance, energy use, load profiles, quality of supply or the inefficiencies of the distribution grid to provide support for decisionmaking.

> *"We don't have a baseline. When we say we improve by 10% or 20%, on what basis? From where? We need that baseline, so at least we can plan for 5–10 years and actually show the tangible input."*

> *"Nobody has done a study to measure the inefficiency of the distribution grid... so because of that absence of knowledge, it's difficult to estimate the magnitude of the problem."*

Additionally, several of the interviewees expressed their unawareness on what other actors were working on or what they had achieved, as information and outcomes from projects are commonly not made public. There were opinions that the willingness to share information publicly or between various parties is low. However, one interviewee added that studies conducted by e.g. international development agencies "have always been shared".

Another interviewee thought that there had been progress on reporting and sharing information both in the public and private sectors. The private sector has been contributing to address the reliability issues with initiatives such as an electricity supply monitoring initiative, which aims to provide data on "the true cost of low-quality power in Kenya and Sub-Saharan Africa". The initiative is funded by the World Bank and managed in Nairobi by an energy consulting company, whose representative explained that five per cent of GDP might be affected by blackouts and low quality power, but no one has collected accurate long-term data on blackouts and power outages before.

5.8 Access to financing

Financing renewable energy and energy efficiency projects has been a common barrier in the sector, and according to the interviewees, although there has been major improvements in the availability and accessibility of financing in the recent years, there is still room for improvement. There is also lack of awareness on the available financing options among both businesses and individuals.

It is mandatory for energy intensive industries and facilities to conduct energy audits. According to one interviewee, energy audits are conducted and energy efficiency measures identified, but the measures are not always implemented in practice due to lack of financing or awareness and adequate information on how and where to apply for financing. Financial players also might lack the understanding of technology and vice versa. A representative of a business incubator also mentioned that concerning financing innovations in the energy domain, few of the companies are investor-ready in terms of their institutional and operational capabilities.

During the past decade, various financing programmes targeted especially for renewable energy and energy efficiency projects have been established. According to interviewees, funding is development-driven, with mentioned financiers including the World Bank, which is involved in several large power sector projects, Sunref, a renewable energy programme driven by the French Development Agency, the African Development Bank and recently also the European Investment Bank and several other institutions. An interviewee from a financing institution had noticed an increased interest from equity financiers and commercial lenders especially in the pay-go solar sector, adding that only a decade ago "there wasn't really any investors".

Generally, investors consider renewable energy projects risky investments with high upfront costs and long payback times. An interviewee commented that this is due to the low feed-in-tariffs, which should be revised in order to attract investment in renewable energy projects. The high interest rates, estimated between 18–24% by one interviewee, also reduce the economical viability of investments. Another interviewee commented that it is difficult for both businesses and individuals to get affordable loans.

Some noted that access to financing has improved due to e.g. various credit loans and micro-financing institutions dedicated to renewable energy technologies. Some thought that capital is no longer an issue, as there is a lot of available funding, but more innovative financing mechanisms and business models are needed along with legal structures to support them. Examples such as crowd-funding and performance-based models for financing renewable energy and energy efficiency projects were mentioned.

5.9 Quality and standards

Quality issues were considered common among e.g. solar home systems, but based on the interviews, increased competition, improved standard and label requirements and awareness creation has reduced the amount of poor quality products on the market.

There has been a large flux of imported solar PV products to Kenya and other

SSA countries since the 1990's. An energy consultant mentioned that all the systems installed back then had eventually failed without no one to fix them, and the failed systems often end up thrown away. Although there is increasing of awareness and skills on maintenance and repair of the systems, some doubted whether it is enough.

Products such as solar panels, LED lamps and battery systems are sold in small shops and kiosks, which are often selling "substandard products at very low prices", according to interviewees, while better quality goods are often more expensive. It is common that people purchase the cheapest or counterfeit products, only to notice that they stop working shortly after, which reduces the trust in such technologies:

> *"Quality is important, because it leads to trust in the technology, which leads to more adoption, which leads to more trust and more adoption. Failing systems do exactly the opposite, which is disastrous for Kenya."*

> *"If a solar system fails... since they don't understand why, they're going to say it was a bad product. That gives solar a bad name and people stop trusting the technology."*

> *"If I buy a LED lamp and it doesn't work, then I'll shy off from wanting to use energy efficient products."*

This is mainly a question of consumer awareness, while companies have also failed to provide adequate maintenance and services for the products:

> *"These companies selling the solar, they have created a bad reputation for themselves. The issue of customer service is quite foreign for them, and quality... If there's a malfunctioning, what happens is the clients will just throw it away."*

> *"The clients sometimes don't understand, not aware of the quality issues. We had a lot of them with solar hot water and that needs to be addressed."*

> *"A lot of users still don't know about quality, especially in normal households, so I think they still need advocacy... I think solar companies are making inputs there to establish themselves and offer good quality service with the installation."*

According to an interviewee involved in the technical committee of the Kenya Bureau of Standards, a quality standard for solar PV products was recently adopted, which was aimed at creating awareness and customer ability to differentiate between good and bad quality, as well as reducing the amount of poor quality products, although they added that "of course there are still leakages of some substandard products coming in from I don't know where".

Another interviewee mentioned that the problem with standards has been the direct use of international standards, while operating conditions and system requirements in Kenya are different. Domesticated standards on systems and their installations would help building up people's confidence in adopting the technologies.

Strathmore Energy Research Centre (SERC) conducts quality assurance of solar PV systems in Nairobi. According to an interviewee from SERC, solutions like product label and standard programs or mandatory testing of imported products are currently looked into, while the creation of public awareness on the quality and correct use of technologies would be at least equally important. The tendency of consumers to buy the cheapest, often poor quality products causes a loop:

> *"You buy a poor quality product, it fails, you buy another one, it fails... because it's cheaper. Also for the one selling the products, they stop buying the good quality things and start selling the poor quality... Information out there, especially linked to quality and how to use the systems, is the biggest issue."*

5.9.1 E-waste

The quality issues in a large amount of imported products together with the lack of sufficient maintenance and recycling practices and awareness has raised serious concerns about electronic waste. Four of the interviewees brought up the issue, explaining that the failed products simply end up thrown away at landfills, as there are no established recycling mechanisms, neither do the products usually come with decommissioning or sufficient warranties. The companies selling the products have no mandate to address the recycling and maintenance of the products. A SERC representative was especially worried about battery systems, which have a large carbon footprint and are prone to failure as a result of misuse and high temperatures.

5.10 Skills and expertise

Lack of skills and expertise was a topic discussed by many interviewees, although there had also been clear improvements in the availability of training programmes, capacity building initiatives and formal education such as university degrees related to energy.

Universities in Nairobi, such as Kenyatta University, University of Nairobi and Strathmore University, which also hosts the SERC, offer degrees in energy technology and energy management. The interviewees commended the private sector which has become active in energy related training and awareness creation. Examples include the Centre of Energy Efficiency and Conservation (CEEC) hosted by KAM, which "has also been able to create capacity in the energy sector" by e.g. training certified energy managers and energy auditors. According to interviewees, also other industry associations, such as KEREA and AEPEA, as well as the international development ecosystem and "a bucket of NGOs" have been actively contributing to training and capacity building in the sector.

The interviewees expressed that in the near future, there will be an even larger need for both technical expertise as well as energy sector planning expertise. The availability of long-term expertise was mentioned as a hindrance:

"What we get in the region is high-level expertise that is available for a month or two, international experts. They come in and they're useful, but they will not help you establish a program and keep it running."

Some interviewees saw the energy sector as a field for prominent opportunities in creating new businesses, services and jobs. One researcher believed that the sustainable energy transition has significant potential regarding job creation and income generation, reducing the issues of poverty and unemployment in Kenya. Another interviewee also commented that the "sustainability" of energy also necessarily includes the impacts on economy and well-being, such as employment. Therefore, they believed that the transition to sustainable energy "could be solving more problems than electricity".

5.11 Collaboration, coordination and long-term planning

Lack of collaboration and coordination was seen as an issue on local and national levels. The urban energy domain is loosely defined, and in contrast to rural energy, there are no dedicated efforts or institutions working on urban energy. Disconnection between actors in the energy sector or between different urban stakeholders was considered to cause delays and overlaps. According to several interviewees, communication, coordination and collaboration are generally inefficient and information is not shared between different actors.

"I think the industry is very separated and everyone is doing their own thing in their own corner... You often find two people running the exact same thing. There's a lot of duplication, driven by wanting to have access to funding."

"Everyone is doing something separately and I do believe there's a bit of overlap all over the place... They're all looking at the same city, and there's huge opportunity to bring them all together."

"The actors are disconnected, they really need to work together to enhance the energy sector and the adoption of sustainable energy. Disconnection between expertise, financial, government, also the international organisations."

More coordination and collaboration was clearly called for by several interviewees. One of them mentioned that creating awareness and sharing information could be encouraged by organising more events and forums to bring multiple actors together. Another one thought that the events, workshops and other networking activities are there, but the issue is more of an institutional nature. Discussion on urban energy issues happens only on an ad-hoc basis, whereas continuous and consistent efforts are completely missing. They suggested that there is a lack of institutional focus concerning urban energy, as all the national agencies have to prioritise rural electrification. Such dedicated efforts would be required to drive urban energy issues forward:

> *"There is no institutional base... that critical mass of expertise for urban energy issues. That's completely missing, no group working on urban energy on a regular basis."*

Urban energy is, as another interviewee put it, "one of those things fallen in nobody's hands".

The industry and professional associations were seen as major catalysts for improved collaboration in the energy sector, as they have been able to "bring all the energy professionals together". One association representative told that they are also supported by and working closely with the government, which they are "proud to be associated with". Other association representatives also mentioned that the associations are well recognised by the national government. Associations were also perceived to provide "on-the-ground experience and continuity".

In addition to associations, the interviewees saw that the influence and recognition of the private sector had increased. The consensus among interviewees was that the private sector clearly works more efficiently than the public sector, while one interviewee also noted that private sector organisations are often not willing to work with the public sector due to its inefficiencies and bureaucracy.

> *"Some things really run well driven by the private sector... Private sector is very important in developing employment opportunities, innovation, make things more efficient, also revenue for the country."*

5.11.1 Lack of long-term planning

Lack of long-term planning was considered a major system level hindrance. The interviewees experienced that various issues tend to be addressed in a reactive rather than proactive manner, resulting in "quick fixes" instead of long-term solutions. As one interviewee phrased it, people "start solving problems when things are failing", and another stated that problems are not dealt with until "they see a problem at their doorstep". A third one noted that the issues caused by the reliance on hydropower woke people up into the fact that the energy sector cannot afford "the luxury of not being proactive":

> *"We were very heavily dependent on hydropower. Then, due to climate change, there was a drought for a long time... that woke people up, taking up energy efficiency and renewable energy... Initially, we were acting because something has happened, so we learned our lessons... Try and look at the problem before it happens and be more proactive."*

Long-term planning becomes difficult with the rapid growth of Nairobi and the many urgent issues and needs to be addressed. One interviewee thought that even the rapid population growth does not necessarily have to be a bad thing, if it is planned for beforehand, as opposed to "just reacting".

The interviewees brought up several practical examples of how the lack of long-term insight and coordination had led to awkward end results, such as the delayed transmission line for the Turkana wind power plant, or the railway project, which was supposed to be powered by electricity from a new geothermal plant:

> *"The railway could have been powered entirely by electricity, taking a good 500–1000 MW, but they chose to have it with diesel, because at the time they started planning, the power plants had not been built. But the power plants were completed before the railway... They were actually planning to devote [the geothermal plants] to the railway, but now, idle capacity on a geothermal plant and you're running a railway on diesel."*

The fact that the county officials change every four years was seen as another barrier for long-term planning specifically at the county level:

> *"When we work with the local governments... we do so much work for four years... Then people change, someone totally different, and you start again. Every election period you do tangible work for one year. First year they're getting used to their job, second they start listening to you, third year they do some work, and then they start electioneering."*

> *"The previous county government had actually started the process of developing an energy policy... Then there was the change of guard and everybody involved was taken out, and now there's a new set of people and they haven't prioritised this... Whatever initiatives had been started, they just got cleared out."*

5.11.2 Linkages between urban stakeholders

Several interviewees thought that there would be good opportunities for collaboration in the urban energy domain, but consistent efforts are missing. One interviewee thought that especially the county government and the utility should put some sort of collaborative effort into urban energy issues, whereas another one thought that there is no "sufficient chemistry" between them.

A utility representative wished for more interaction and information sharing between the different actors involved in urban infrastructure systems:

> *"There is a total disconnect. Not just Nairobi county, but all those involved in infrastructure... We don't have a lot of collaboration in the planning departments, and therefore, there is a lot of conflict."*

This disconnection, they thought, causes overlaps and significant delays in implementation of projects, "as you try to sort out who should do what". Better cross-sectoral collaboration would save time and resources, as there are currently a lot of inconveniences and inefficiencies related to urban infrastructure developments and the provision of various services in the city. They brought up the need for a continuous city planning programme, which would be beneficial for all the stakeholders, all of which are currently facing many similar challenges on their own.

"We have multi-agency meetings, but most of them happen in a reactionary manner... the meetings and initiatives are basically project-based other than a program... We don't have a standing committee or program to bring everyone together for planning purposes... As it becomes more and more necessary, and becomes more and more expensive for everyone, there will be a stage where we must talk, because we are reaching a gridlock."

Currently, it is an issue that "people who are serving the same customers do not share information". A utility representative told that they had been putting effort into digitising their maps, allowing planning and design to be done from the office. They hoped that other infrastructure service providers would adopt the same approach, and that such information could be shared between different actors.

The interviewees thought that in general, the linkages between energy and urban development in Nairobi are weak. People in charge of county planning and county-level policy do not have energy in their priorities, and for example, construction projects and other developments do not take energy into account as well as they could.

"People around the construction or development sector, urban planners, designers, engineers, we just keep talking to each other, we don't talk to anyone else."

5.11.3 Linkages between levels of governance

The interviewees considered that the capacity at the county level to address energy issues is insufficient. At the county level, energy is not given the weight that it is given on a national level. Kenya has the Ministry of Energy, while at the county level energy is merged into one department together with environment, water and other natural resources. One interviewee mentioned that in the new county constitution, county governments are supposed to come up with energy sector plans that correspond with the national energy plans, but so far, only some counties have done such plans. Another interviewee saw that the county government is not incentivised, "apart from their own energy bills", to address any energy issues. It was also noted that the county constitution is still very new to Kenya, and it would be necessary to "build capacity for these counties to start thinking about their energy problems".

"They [county government] simply don't have the capacity... to be able to understand the issues better and to be able to implement solutions that are beneficial."

Some interviewees thought that energy is not a priority at the county level simply due to the existence of more urgent issues to address, such as the country-wide water shortages, while people are "still struggling with access to housing and access to basic things".

> *"Energy is not a basic need, so to speak, according to most of the guys on the street, according to the county government. Basic needs are water, affordable housing, affordable transport. Those are some of the priority areas for the county government."*

> *"It's just an issue of day-to-day issues, to connect people, to provide water to people. For someone who's drowning, the most important thing is to stay afloat. The person drowning is not thinking where I am going to get rent for next month, just in a mode of staying alive. I think we're in that mode. So many immediate needs, there's not enough time set aside for long-term planning, even less time for implementing those long-term plans."*

An interviewee from an energy industry association wished for more delegation of regulatory roles and authority on the county level than national level. As county legislation is more binding than national, it could improve the efficient implementation of regulations, because currently the regulator "does not have the capacity to reach out to 47 counties". Additionally, the needs and issues related to energy are very different in different counties. While some interviewees pointed out that the local governments probably have to prioritise more urgent issues than energy, such as food, water and waste management, some thought that they just lack the commitment and political will:

> *"The guys who have really been influencing policy and some of these technologies are national institutions. The county government supposed to be at the forefront, but that has been lacking 100%... It's basically just lack of commitment, from national government and county government, but biggest let-down has been the county government of Nairobi."*

Another interviewee agreed that the county governments should have more agency and resources to address energy issues. However, they also thought that national agencies are not willing to give up the authority that they have.

> *"I think it's an issue of who controls what... Major disconnect between national and county government in terms of policy, in terms of communication, in terms of deployment, there's a major gap."*

5.11.4 Centralised control in the energy sector

Several interviewees mentioned that the energy sector is highly controlled by the government, which is also the largest shareholder of the national electricity utility, and that government support is essential for any projects in the power sector. Another interviewee stated that the power sector is dominated by "the rich and the powerful" in the country. Many pointed out that issues in the energy sector are tangled with various other political interests in Kenya. For instance, one interviewee believed that the new Energy Bill is delayed on purpose, since it would allow individual users to sell electricity to the grid, improving the attractiveness of decentralised generation:

> *"Because they make money from selling electricity, they wouldn't want it any other way. There's only so much they can deny from an individual."*

There has also been some discussion on whether Kenya Power should split in several regional utilities in order to better serve the needs of different regions, as it would allow faster responses and better incentives. According to an interviewee from an energy industry association, splitting the utility and giving more authority to the counties was proposed in the new Energy Bill, which has been on hold for a few years. The same interviewee thought that such decentralisation in the power sector is not likely, as the utility will choose to stay centralised due to "vested interests":

> *"There is too much at stake that they didn't want to let go of, but it's probably going to happen organically."*

5.11.5 Conflicting interests, corruption and lack of trust

Various political and personal interests are at play in the energy sector, according to several interviewees. Political interests and corruption were considered a "major hindrance" and a common cause for e.g. delays in various projects. Some mentioned that there had been discussions and plans of building a waste-to-energy plant in Nairobi for a long time, and they thought that the reason for the lack of implementation was "political interests" or "corruption". Additionally, the delays and inconsistencies with the Turkana wind power plant, the diesel-powered railway project, fluctuating electricity prices, the relatively low employment of Kenya's geothermal generation potential and the Lamu coal plant were associated with political interests.

> *"I think it's politics... sometimes things don't move so fast here as you'd like to see... If the political will is low, it takes a lot of time."*

> *"That's pure corruption. It's the only reason... because the person wasn't going to be gratified personally."*

> *"It's just political interests, I'd say. There's a Swahili saying that loosely translates to 'the owners of the country'. It's the cartels, political families, businesspeople, business interests... The coal doesn't make sense in Lamu, it's not even cheap... Its polluting, the coal is being imported... It doesn't make sense, but it's the political interest."*

Some interviewees thought that there are people with questionable interests involved in the energy sector and projects related to energy and infrastructure, because it is "a place where you can play with corruption", people involved are "able to make money on public offers", "everyone has to get their cut from something" and "there's always someone who wants to benefit from it". Another interviewee simply stated that Kenyans do not trust their governments and politicians.

> *"I don't know about your country, but people are corrupt here. The energy sector in this country is controlled by cartels... The use of diesel engines in this country, not because there's no power, but because there's some cartels somewhere who own those kind of installations in this country, because they have to make money."*

The same interviewee added that the cartels have "always been there" and are difficult to get rid of:

> *"The cartels have been there and they continue to be there... There are some guys in senior government positions who are willing to be able to get what is in the system... Cartels in the energy sector, I can tell you, they're many."*

Several others had similar statements, while some were less direct about it, as one interviewee who commented the cost of electricity:

> *"There's some gray area there... Someone was actually saying there is a cartel going on here, but there's really not much you can do about it."*

One argument in advocacy of a more decentralised approach to electricity was that decentralised generation and distribution could reduce the interdependencies between energy and political interests:

> *"It's going to change the way how these people's energy needs are going to be met, and they don't have to rely on the national government and good political will... "*

One interviewee pointed out that if there was more information shared in public, there would be less corruption. According to them, when agreements are being signed "behind closed doors", corruption is more likely than when information of upcoming initiatives and projects is shared openly.

Issues related to political interests or corruption were brought up by the interviewees in various contexts. Some of the interviewees only brought up the topic after the interview if at all, while some interviewees talked about such issues very openly and without hesitation. One described how the issue of corruption is not driven by intentional wrongdoing of self-interested individuals, but instead is a complex, embedded social mechanism:

> *"No one wants it, I think of corruption so that everyone participates in it. It's all of us in the system... It's a complex problem. How to not participate in the system... Corruption is more of a societal problem. We as Kenyans have kind of accepted that that's how we're going to live, but not really accept it... a system that punishes you if you're not corrupt."*

5.11.6 International development ecosystem

Development agencies were commended on their achievements on electrification and renewable power generation projects in Kenya. The Last Mile Programme, which managed to connect a large share of Kenyans to the grid during the recent years, received funding from several development partners. The international development ecosystem was also noted to have an integral role in capacity building, training and awareness creation.

> *"We don't really have a green community here the way you have them. . . consumers who want to buy green products and to be green, push politics to be green. That's a very small group in our region, and that kind of international push helps a lot. It gives it a certain validity and makes it respectable and acceptable on policy level."*

One researcher thought that the energy sector in Kenya is actually driven by development funding:

> *"The industry is driven by donor-funded money. Donors are the most powerful actors, they set the agenda. Whatever they fund is what people will run towards. If they set the right agenda, people will do the right things."*

While the interviewees seemed to agree that international collaboration and the achievements of certain development actors have been essential for the recent improvements in Kenya's energy sector, they also brought up several issues with the international development ecosystem. The dependency on donor and aid funding was not seen as a good thing, as the interests and incentives of the development agencies are not necessarily aligned with those of the receiving party. One interviewee explained that it is also the reason for much larger international interest in funding e.g. solar PV systems than clean cooking technologies, where there is a greater need.

The same interviewee described how the international actors tend to "push" their own agendas and interests, and that there are "so many foreign companies that are coming to introduce their technologies in this country":

> *"Like USAID, on the form that you fill it says 'on every dollar that we invest, how many more will it leverage on US products'. It's not even a secret. . . the money will always go to a US company. They even ask, which private companies will be interested in this after it's implemented. It means that they're creating market for themselves."*

> *"That's like development assistance 101. . . where is the biggest opportunity, and next you're selling technical products and consultancy. . . examples like mini-grid systems and solar homes."*

Short project cycles were mentioned as another issue related to development projects. The development programmes and projects last for a limited amount of time, while the initiatives are often set out to address issues that would require more long-term planning and commitment.

Another issue with development assistance in Africa in general, according to one interviewee, is that the allocated resources are insufficient compared to the goals of the initiatives. According to them, the success of Kenya's electrification programmes were partly due to the specific and clear goal of increasing the amount of connections.

> *"SREP [Scaling up Renewable Energy Program] gave Tanzania 50 million dollars to 'transform energy access'. 50 million dollars? That's what Manchester United pays for a player... It's a lot of money, yes, but very little against the need that it's set to address."*

Projects driven by development agencies were also perceived inefficient due to the lack of feedback loops. According to one interviewee, private sector initiatives are more efficient, since they are more responsive to the end users and get direct feedback from the people affected, e.g. through purchased amount of products. In contrast, development agencies "look the other way", as they are more concerned with the satisfaction of donors than the people in the receiving end. The same interviewee pointed out another characteristic difference between the development ecosystem and the private sector, which is the lack of self-learning, iterativeness and flexibility, which they thought would necessary to build into development programs.

The development agencies were also thought to often have misinformed perceptions of the real development needs of the receiving party, since they tend to "rush into giving", not taking enough time for feasibility studies and analysis of the actual needs.

> *"Find the real need. It's not only about throwing money on the problem, I don't see it having such an impact."*

> *"If I don't have salt or paper in my house, you cannot come in and say 'I've done this analysis and you need an air conditioning system.'"*

One interviewee also noted how in many development projects, a large share of the money seems to end up on administration with little tangible impact. Overlaps and miscommunication occur, as coordination with local actors or among the NGOs themselves is insufficient or inefficient.

> *"Obviously, we end up not making as much impact as we would with better coordination... These NGOs, they're just more funded but like the government, they're not efficient, takes a lot of time, disattached... I think it's an issue of communication and coordination."*

Lack of involvement of local expertise and insufficient understanding of the local context was perceived as another issue. One interviewee pointed out that in feasibility studies as well as academic research, if the researchers do not "talk to the locals and find the local experts", they likely end up with misinformed results and "just think they are finding the problem". Additionally, with the example of international solar PV companies trying to introduce warranty systems "that people are not going to trust anytime soon", they illustrated the point that the international players often lack understanding of the Kenyan context.

> *"In most countries you do warranties, so for you warranties make a lot of sense. You trust your government to have your best intentions, you trust your neighbour to not steal from you. That trust between society and people does not exist here... Something like warranty is very hard to make work here... There's a lot of foreigners in the energy sector here, pushing for warranties coming from a point of not understanding... I would say that when it comes to implementing working solutions, use established, working trust networks. It is easier to build on it than to change an entire culture."*

Another interviewee thought that developing countries should also be able to negotiate better with the development agencies and to hold on to their own development priorities and agendas:

> *"The SREP team went to Ethiopia, told them we have this 50 million dollars and this is where it goes. The Ethiopian government told them this is our development footprint, we prioritise geothermal... take your 50 million, it's wasting out time... so they went away. They came back later and put the 50 million on geothermal."*

> *"We need to negotiate better. We need to get away from feeling sorry for ourselves, feeling that the world is conspiring against us and all these things. Of course there are some historical things that have happened, but who's going to change history."*

5.12 Transportation fuels

While electricity generation is relatively clean in Kenya, the transportation sector is heavily dependent on imported petroleum products and a major source of pollution and CO_2 emissions. A representative of an energy industry association stated that in Kenya, transportation is "the number one source of emissions". Many interviewees brought up the issue of pollution, as Nairobi suffers from poor air quality.

The road infrastructure of Nairobi is in bad condition and there are no bicycle paths or public bus rapid transport systems. The closest option to public transportation are the mini-buses, "matatus". Daily traffic jams are another significant challenge in Nairobi. As one interviewee described it, the reliance on personal vehicles, mainly cars and motorbikes, and poor availability of mass transit systems is very inefficient use of high cost fuels. Proper mass transport systems could both reduce energy use of the transportation sector and the traffic jams, which also have an economic impact:

"There is a huge economic loss in the traffic jams. So if you could switch to mass transit system, you would not only reduce consumption, you would have a huge economic impact... Dar es Salaam [the capital of Tanzania] has a functional bus rapid transport system and it's working very well, so if it can work there, why not in Nairobi. There has been talk about it, but nothing much has been happening, not quite sure why."

There was a lot of interest in electric vehicles, although many who brought up the topic thought that the adoption of electric vehicles in Nairobi will not happen in the near future. Electrification of transportation could contribute to reducing the air quality issues in the city. However, the ability to charge electric vehicles would require either more reliability from the grid or better viability of off-grid charging solutions.

There had been discussion and plans on electric railway projects, and one interviewee suggested that public service vehicles and buses could run on bio-based fuels or electricity in the near future. One interviewee had also heard about plans on an electric motorbike pilot project motivated by the need to reduce the pollution issues of Nairobi, but they added that with electric vehicles comes the issue of recycling batteries, which would need to be solved first, as recycling and waste management are still unsolved issues in Nairobi.

5.13 Cooking fuels

The sustainability of cooking fuels and technologies has been under discussion in Kenya and many interviewees brought it up as a major energy challenge in the country. Traditional fuels, such as firewood and charcoal, are used by most of the population especially in rural Kenya, but also a large number of urban residents especially in low-income areas. The main challenge was charcoal, which causes environmental issues across the country. Most of the charcoal production happens on an unsustainable basis. The widely practised logging for charcoal production causes deforestation, which worsens droughts and scarcity of water.

The wide use of charcoal is also problematic, because "people who use the charcoal are oblivious to the impact it's having in the majority of areas". A significant share of the charcoal produced in Kenya is consumed in the Nairobi area, which also raised the need "to think clean cooking solutions especially for the urban poor". An attempt to cut down unsustainable logging had been made by setting regulations on logging. However, the regulations are weak and difficult to enforce:

"The use of charcoal is not banned, but transportation is. So people just find ways of transporting it without being noticed, because selling is no problem, but transporting is. So it's a very weak and unintentional regulation."

Other sources of biomass are legitimate alternatives as cooking fuels, but one interviewee estimated that more than 90% of people use unsustainable biomass as a source of cooking energy. Unsustainable biomass depletes the soil, which is a problem in a country with mostly arid or semi-arid lands, severe droughts and vulnerability to the effects of the changing climate.

An alternative for firewood and charcoal are briquettes made from waste material, such as agricultural waste. There are also briquettes from unsustainable sources, which is an issue for food security. The interviewees reported that the briquette industry is gaining more market share. Still, there were wishes that the briquette industry could grow faster, as the unsustainable use of charcoal needs be cut down more rapidly.

Several interviewees thought that although LPG is not carbon-neutral, it is still "way better than the existing options". LPG is commonly used for cooking in urban areas, especially among the middle-class. One of the barriers for using LPG is the cost of the tanks, which makes it an unavailable option for most of the lower-income population. According to a representative of an energy industry association, the logistics, storage and delivery of LPG had also been improved, making it more cost efficient. These have reduced the structural and market barriers for a wider uptake of LPG. One interviewee raised the concern of insufficient regulations on LPG, since the gas often comes from unknown sources.

5.14 Summary of the empirical findings

There was a consensus among interviewees that the reliability of grid supply was the main challenge in the electricity sector in Nairobi, as power outages and power quality problems are common, although the situation has improved in the recent years. Because of the frequent blackouts, diesel power generators are extremely common, adding to the pollution issues in the city. The distribution infrastructure is also highly inefficient. The electricity demand is predicted to grow significantly, which was seen as a challenge to the grid.

Access to electricity is the main concern on the national level, whereas Nairobi is mostly covered by the national distribution grid. A majority of grid electricity comes from renewable sources and the sufficiency of generation capacity was not seen as an issue, while the reliance on hydropower had been a challenge. A shift towards a more demand-led approach to energy sector planning was perceived necessary. Affordability of electricity was considered an issue, as the prices are volatile and a majority of low-income households cannot afford modern energy. It is also technically challenging to provide electricity access to informal settlements for an increasing number of low-income urban dwellers.

Disconnection between various urban actors and between levels of governance was discussed. Lack of long-term planning and institutional base concerning urban energy were also noted. The interviewees thought that coordination, collaboration and information sharing between urban stakeholders as well as between levels of governance could be improved, while especially the various industry associations were seen as important facilitators of collaboration. It was suggested that urban energy is simply not a current priority for any institution in Nairobi, as there are more urgent basic needs to be addressed, while the focus of national actors in the energy sector is on rural electrification.

Lack of financing was no longer seen as an issue, but lack of access to it was. International development partners and financing institutions play a large role in funding power sector projects, but some interviewees thought that they often lack understanding of the local context and that development-driven projects are not always well coordinated or targeted towards the real needs.

Lack of awareness and insufficient availability of information were brought up by several interviewees in various contexts. Many were worried of quality problems with energy products and the emerging issue of e-waste. Availability of training and expertise had improved in the energy sector.

The interviewees brought up several opportunities which they saw as potential solutions to some of the urban energy challenges. These included various district scale infrastructures, electricity storage, net metering and waste-to-energy plants. The interviewees noted an increasing interest towards solar PV, although it was mostly discussed in terms of rural electrification. There was a consensus among interviewees that the most significant recent developments had been in regulatory frameworks, such as the regulations on SWH systems and energy auditing. The interviewees thought that the regulatory frameworks are among the main drivers of a sustainable energy transition, but county level energy planning could facilitate the adoption of new policies more efficiently.

6 Discussion

In this chapter, the findings of the study are reflected on and compared with the theoretical concepts presented in the literature review.

This thesis studies urban energy transitions in emerging markets with a case study of Nairobi. The aim of the study was to identify the urban energy challenges and barriers that hinder the transition to a sustainable urban energy system. The factors analysed in the study were initially identified from existing literature, while allowing new themes to emerge in the data analysis process. Based on the interpreted findings, proposed answers are developed to the research questions of the study:

1. What are the main urban energy challenges in Nairobi?

2. Which barriers hinder the transition to a sustainable urban energy system in Nairobi?

The first research question is answered in detail in Section 6.2 and the second in Section 6.3. The findings suggest that the identified urban energy challenges and barriers to the urban energy transition are mostly aligned with the existing literature.

6.1 Transition dynamics in the urban energy regime

In this section, the urban energy system of Nairobi is positioned in the context of the multi-level perspective on socio-technical transitions to understand the dynamics of change and stability in the system. As distinguished by Geels [20], a socio-technical regime in the electricity sector can be viewed to consist of three main dimensions: 1) the networks of actors and groups, 2) the established formal and informal rule sets guiding their activities and 3) the existing technological configurations of the electricity system. These dimensions of the regime are discussed here together with endogenous change processes, landscape pressures and niche developments as possible indicators of an ongoing transition in the socio-technical system.

6.1.1 Actor networks

The government and governmental bodies have a well-established role in the electricity regime. The dominant regime actors are national organisations, such as the utility and the agencies under the MoE. There is significant landscape-level pressure to electrify the rural areas of Kenya, which enforces the current technological trajectory of extending the national grid coverage. At the urban level of the regime is the county administration, which again is under the pressure to provide basic services for the growing urban population, which is still lacking access to adequate housing, water, transportation and cooking fuels, electricity not being on the top of the priorities. One barrier for the urban energy transition is therefore that sustainable energy is not a priority at the urban level nor is there sufficient institutional capacity and capability for implementing sustainable energy policies and measures at the urban scale.

There are no institutions or dedicated programmes focused on urban energy. Not all regime structures can be influenced from the local level alone, but while city administrations may lack the financial and regulatory resources to transform their infrastructures, they can, with other actors and networks, have sufficient capacity to imply changes on institutional structures and create new organisations, which may facilitate more fundamental change in the long-term [1, 9]. Partial delegation of resources and regulatory authority from national level to county level could improve the capacity of counties to address their urban energy issues. Local governments could work with their national counterparts to ensure the local implementation of relevant solutions that can drive the transition towards clean, affordable and reliable energy.

Public or private utility service providers affect the development of urban services within a city [1], and are therefore influential actors in the urban energy regime. KP operates, maintains and develops the national electricity distribution grid, which makes it a key actor in the electricity regime in addition to the agencies in national and county governments. There has also been discussion on whether the utility should split in regional utilities to be better able to serve the needs of different regions.

National governments and international development agencies have an enabling role in the urban energy transitions of emerging countries [2]. Funding of power sector projects has been development-driven and development agencies also facilitate awareness creation and capacity building. While their impact enables significant developments in the sustainable energy domain in Kenya, it may also be problematic in cases where understanding of local context and involvement of local expertise is insufficient, or when the interests of international actors are not well aligned with the needs of the receiving party. Flexibility and long-term planning should therefore be integrated in development programmes. The issues of energy-related emissions and climate change are not confined to boundaries of countries and continents, and the genuinely global nature of energy and climate challenges requires mutual responsibility on finding and implementing solutions for them, especially since emerging countries often lack the capacity and resources to do so. Instead of simply exporting products and technologies to emerging markets, holistic and inclusive approaches and understanding of local context are essential in order to ensure the long-term sustainability and viability of solutions.

The role of industry associations in facilitating the energy transition was acknowledged by respondents. According to Geels [16], professional associations, branch organisations and other special interest groups are important in socio-institutional change processes of the regime and niches. They are capable to impact how the shared visions and frames are built through participating in the negotiation of collective rules, goals and policies. In Kenya, such associations have been able to create dialogue between various actors and affect policymaking.

Urban energy systems can provide resources to host and develop niche technologies [2], and the implementation of new technological innovations is commonly initiated in cities [1]. Nairobi hosts several research organisations as well as business incubators and hubs, some of which are targeted specifically for climate and energy innovations.

Support from the government and other regime actors is perceived instrumental to the success of niche technologies.

6.1.2 Guiding principles

While policies concerning the urban environment are typically exercised on several layers of governance and a number of cities are developing local energy plans and policies [1], Nairobi does not have local energy policies in place. Sector planning is mostly done at the national level, but the new county constitution is intended to allocate more legislative power to the counties.

Government interventions strongly influence the guiding principles through introduced policies and regulatory measures. Kenya has introduced several policies to encourage the adoption of renewable energy and energy efficiency, for which the work of ERC was commended on. The introduction of the delayed Energy Bill would further increase momentum for the adoption of solar PV technologies by introducing net metering, which makes decentralised generation more feasible. The interviewees suggested that the delayed introduction of the Bill is due to resistance from key regime actors, as it would reduce their dominance in the regime. However, the utility expressed that the utility is accommodative to these new developments and considered them necessary.

The recent regulatory measures and the introduction of initiatives such as the CEEC implies that energy efficiency is already seen as an integral part for the growth of the Kenyan economy and industries, and therefore supports the goals of regime actors. The role of energy efficiency in achieving the government visions of Kenya as an industrialised middle-income country by 2030 is acknowledged in long-term strategies and official documents [38], whereas the role of clean and renewable energy technologies are emphasized in national climate responses [48]. The LCPDP notes that local resources, such as geothermal and wind, are more cost-efficient than imported fuels, such as coal and nuclear, and should be favoured when expanding generation capacity [12]. Therefore, favouring local renewable generation strengthens energy self-sufficiency, security of supply and affordability of electricity in the long term, while avoiding the growth of energy-related CO_2 emissions. However, the planned additional power generation from coal [40], which is also mentioned in Vision 2030 [38], conflicts with both national objectives and commitments for sustainable energy development and climate change mitigation and adaptation [48].

In addition to the regulations and formal rule sets, various informal practices and socio-cultural factors guide the activities of actor groups. Transitions in socio-technical systems can occur when the levels of the socio-technical systems are aligned and enforce each other [16], which implies the need for shared visions, goals and interests between the actor groups. National actors in the electricity sector are guided by the primary need to increase access, as rural electrification levels in the country are still low. The dedicated efforts of REA and international collaborators to increase electricity access in Kenya have been successful and led to significant improvement in connectivity levels in the recent years, but access to electricity is still the primary concern when talking about energy in Kenya. In Nairobi, the priorities of county government and other local players are in meeting other immediate needs, while the city is already mostly covered by grid access. In the absence of city-level energy plans and prioritisation, urban energy specifically is not a guiding priority for any interest group.

In emerging countries, international development organisations are often major enablers of energy transitions in addition to national governments [2]. Not all interviewees agreed on whether the international agencies use this position in the most efficient way or whether they are able to target the real needs in the country. The international development ecosystem was criticised for having lacked understanding of the local context and involvement of local expertise and tacit knowledge. External actors may have a limited awareness of the socio-cultural factors at the landscape level, instead imposing the cultural paradigms embedded in their own respective socio-technical contexts. However, the external pressure of integrating sustainability in the electricity sector is enforced by the international actors driving the adoption of renewable energy and energy efficiency. As one interviewee expressed it, this "green lobby" is welcomed and gives validity at the policy level.

Several socio-cultural factors integrated in the socio-technical system could be noted. A lack of trust between and towards actor groups can be associated with the weak linkages between levels of governance as well as between different stakeholders of the urban energy system. Public sector is considered too bureaucratic and inefficient by private sector players, while support from the public sector is seen as instrumental for the success of niche developments and various private sector activities. There is tendency to solve issues in a reactive manner, while proactive approaches and long-term planning would lead to sustained and more efficient solutions. The unwillingness of parties to share relevant information, corruption and various political and personal interests involved in the energy sector were repeatedly brought up, while such embedded societal mechanisms are generally difficult to change [16]. Lack of trust, low availability of information and weak linkages between actor groups might be mutually enforcing mechanisms, resulting in further fragmented operation of actors in the urban energy domain. Measures to improve transparency, horizontal and vertical integration between stakeholders and the creation of shared goals and visions should therefore be further encouraged to facilitate better communication, coordination and long-term planning.

6.1.3 Technological configurations

The high density of population provides opportunities for improved energy efficiency and better integration of services and infrastructures, including electricity distribution [1, 21]. Electricity generation happens outside urban areas, whereas its demand is generally concentrated in cities [1]. Over a half of all electricity generated in Kenya is consumed in Nairobi [12], where there is potential for substantial energy efficient improvements. In the supply side, W2E generation and rooftop solar systems were considered suitable cost-efficient opportunities for local power generation. Solar water heating technologies have made their way into the regime through the introduction of the SWH regulation. In the longer term, electricity storages could provide flexibility that is needed in the grid, while improving the robustness and reliability of supply would be the first priority at the urban level. Currently, power outages and quality problems are frequent due to the unreliable, inadequate and inefficient distribution infrastructure, which is burdened by the unplanned growth of demand and peak loads. Diesel generators are widely used to provide backup power, contributing to the pollution issues and the high cost of power, which has also fluctuated during the drought seasons due to the reliance on hydropower.

At the national level, the electricity access targets drive the development of transmission and distribution infrastructure, as the government and its collaborators are putting great effort into achieving universal electricity access in the country. The rural areas in developing countries have formed a market niche for solar PV systems, which were previously seen as a marginal technology, but are now acknowledged by long-term visions of regime actors. Solar PV is seen as a significant sustainable energy opportunity for Kenya, especially in terms of rural electrification, while its potential effects on employment, economic empowerment and societal wellbeing in the country are anticipated.

Cities can facilitate the sustainable energy transition at the national level and vice versa [2]. Some interviewees suggested different transition pathways for the rural and urban energy systems in Kenya. Urban areas are typically dependent on grid-based infrastructures [1], but there has been discussion on scenarios where solar PV systems and mini-grids could offer competition for the existing grid infrastructure maintained by the monopoly utility. However, Nairobi will likely stay dependent on the grid in the future. The infrastructures are already mostly in place, and although the cost of grid electricity has been high, it is still more cost competitive than alternative configurations. There is a growing interest in on-grid solar PV systems in Nairobi, especially among commercial and industrial actors. The utility has taken several measures to strengthen the grid, such as the introduction of regional managers, real-time monitoring and underground cabling programmes, moving towards a more proactive approach in operations and maintenance. However, the rural areas as well as the emerging urban areas elsewhere in Kenya can increasingly benefit from decentralised approaches in developing their energy infrastructures, and there are high expectations on various district-level infrastructures.

At the landscape level, factors affecting the technological configurations include environmental changes, most notably the impacts of climate change. Due to the reliance on hydropower and the weak distribution infrastructure, the electricity system is vulnerable to changing weather and environmental conditions. The worsening droughts imply larger use of fossil fuels in the generation mix, which affects the cost of power. On the other hand, the local climate in Nairobi is optimal for the energy efficiency of the built environment, as neither heating or cooling is necessary in domestic houses and solar energy can be used for water heating. The geothermal potential in Kenya is significant, providing a cost-efficient, stable and domestic source of renewable electricity. However, the surplus capacity and mismatches between planned supply and demand imply a need for a more demand-led approach in planning power generation projects.

6.2 Urban energy challenges

Main urban energy challenges in Nairobi are related to the reliability of supply, energy provision for the urban low-income dwellers and air quality issues resulting from the use of unsustainable fuels in transportation, cooking and the use of diesel generators to provide backup power. For the most part, the urban energy challenges in Nairobi are similar to the ones previously identified in literature. Additionally, the issue of e-waste is discussed.

Urban sustainability transitions become challenging with the dense population, concentrated economic activities and high energy demand that are characteristic to urban areas [1], while several urban regions in SSA are also affected by fast urbanisation rates, energy poverty and low levels of access to modern energy [9]. The challenges associated with urban energy increase with the rapid growth of the urban population, with the population growth of Nairobi estimated at an annual rate of 4% [14, 34]. In rapidly growing cities, the urban poor commonly dwell in informal settlements [3], which makes the provision of urban services difficult. The lack of proper infrastructure and housing restricts the provision of modern energy in these areas, in addition to issues with affordability. The slum electrification programmes of the utility and development agencies have improved the situation.

Reliability of the electricity supply is a major issue in Nairobi, although it has improved in the recent years. The frequent power outages, power quality problems and high transmission and distribution losses are associated with the inefficient and aging power infrastructure, which is prone to faults and vulnerable to weather conditions. This is aligned with literature, as the quality and consistency of supply is a common issue in emerging countries [1]. The incremental growth of demand due to unplanned and unmanageable growth of the urban population is further straining the distribution network and has led to the inadequacy of distribution capacity. There are no sufficient resources or efforts to maintain and strengthen the grid infrastructure, as extending the grid is a priority. Because of the unreliability of the grid, diesel backup power generators are extremely common, although only afforded by wealthier households and businesses, contributing to the pollution in urban ambient air. Infrastructure issues have been dealt with reactively, but the utility is increasingly adopting a more proactive approach to operations and maintenance.

The focus in Kenya's energy sector has been on ensuring sufficient generation capacity and extending electricity access, but a demand-led approach to electricity is becoming increasingly important. In SSA, the urban energy demand is affected by the changing consumption patterns due to the growth of the so-called middle class [9], which is also the case with Nairobi. The increasing industrial and economic activities are also contributing to the peak and overall demands, which indicates that the insufficient and unreliable infrastructure is becoming more of a challenge.

Access to electricity is relatively good in Nairobi, due to the successful electrification efforts and the slum electrification programmes in informal settlements. However, there are still households, mainly in the informal settlements, without access to electricity, which is common in large cities of emerging countries [1]. Uneven distribution of urban services and infrastructures between various income levels is common in SSA [9], where Nairobi is no exception, even though electricity access otherwise covers most of the urban households. The cost of power has been volatile and on an upward trend, which makes affordability of electricity a challenge.

Electricity access in Nairobi was estimated at 80–90% by interviewees. Although Nairobi is mostly covered by the national grid and the access level is high compared to other regions of SSA, achieving universal access to modern energy services is held back by the high cost of electricity. Provision of affordable, clean and reliable energy especially for low-income consumers is still a challenge. Energy poverty implies lack of access to electricity and the use of cheapest available fuels [1]. A large share of low-income urban residents dwell in informal settlements, where access provision is technically challenging, in addition to which the low-income population cannot afford modern energy, as the proportion of incomes that they have to spend on energy needs is high. The electricity cost is high also for other than the low-income population, while the cost of power is also volatile and the users lack awareness of what the energy bills consist of and how to affect it. Several slum areas have received connectivity due to the slum electrification programmes enabled by development funding.

Air quality is a severe issue in Nairobi, as well as in most of the world's large cities according to WHO [3]. Transportation and cooking fuels are common causes of outdoor and indoor air quality issues in urban areas [1, 3], which also holds true for Nairobi. The largest contributor to pollution in Nairobi is transportation. In the absence of efficient and adequate public transportation systems and bicycle roads, the high amount of personal vehicles and resulting emissions are a major cause of air pollution. The diesel generators used to back-up power supply, as well as cooking fuels such as charcoal and kerosene especially used in low-income areas, also contribute to the air quality problems. In terms of electricity, the poor reliability of supply contributes to the air quality issues, as it implies the need for diesel power generators. Wide-scale electrification of the transportation sector is not relevant in the near future, but improvements in public transportation systems and road infrastructures would reduce the reliance on personal vehicles.

The large uptake of imported energy products, such as solar PV systems, together with insufficient maintenance and recycling practices has led to an emerging issue of electronic waste. It is especially relevant to Nairobi, where there is a high uptake of energy products among other electrical appliances. The increasing amount of e-waste raises questions on how sustainable it actually is to promote the much anticipated technologies, such as solar PV and battery electricity storages, as long as the maintenance and recycling issues are not solved.

6.3 Barriers to urban energy transition

The literature on barriers to sustainable energy focuses on renewable energy projects with techno-economic approaches, which place an emphasis on the financial and economic feasibility and technical performance of renewable energy and energy efficiency technologies. From a socio-technical approach, barriers can be viewed as factors that protect and enforce the unsustainable practices embedded in the actor networks, rule sets and technological configurations of the existing regime.

The literature on barriers to the adoption of renewable energy and energy efficiency technologies was focused on the national level, whereas theory on the barriers specific to the urban scale were derived from literature on urban energy systems and their governance.

In sum, the main barriers for the urban energy transition in Nairobi include the insufficient institutional capacity at the urban level, low awareness and availability of information, lack of collaboration and trust between urban energy stakeholders, lack of innovative financing mechanisms and low access to affordable capital. Recent developments have reduced the hindrances related to regulatory frameworks, skills and expertise and lack of technical standards.

6.3.1 Institutional and regulatory barriers

Enabling policy environment is among the main prerequisites for the transition to a sustainable energy system. The lack of enabling frameworks and policies is a common hindrance for the adoption of renewable energy and energy efficiency technologies [28], but emerging countries are increasingly implementing policies and targets to facilitate the shift to sustainable energy [7].

Kenya has developed national energy sector plans, goals and policy support measures, such as feed-in-tariffs and tax exemptions on renewable technologies. The SWH regulation is a prominent improvement for the energy efficiency of the urban built environment in Nairobi. Industrial efficiency measures, such as the energy audit requirement, are also relevant especially in the urban areas, where there are large commercial and industrial facilities. However, the inclusion of coal in national power generation capacity expansion plans, which is mentioned in Vision 2030 [38] and LCPDP [12], conflicts with the national renewable energy targets and Kenya's national and international commitments to sustainable development and climate change mitigation and adaptation.

Uncertainty in policy shifts has been noted to hinder investment [20], which might affect decentralised renewable energy production in Kenya as the Energy Bill has been delayed. The introduction of net metering would improve the feasibility of decentralised generation, allowing consumers to act as prosumers. Otherwise there are no major barriers in current policy frameworks concerning renewable energy and energy efficiency, for which the work of the regulatory agency was commended on. Industry associations have also played a significant role in the development of favourable policies and regulations concerning the energy sector, while ensuring stakeholder participation in decisionmaking.

There were doubts on whether policies and regulations are actually implemented in practice or whether they only work "on paper". However, most of the regulatory developments, such as energy audit requirements and the SWH regulation, were relatively new, which suggests that the long-term effects of policy adjustments might not yet be fully visible, although their increased uptake had been clearly noted.

The literature on barriers to energy transitions was mostly concerned with the national instead of the urban level, but literature on urban energy systems acknowledged the significance of institutional support across several relevant levels of governance. National energy policies are important enablers of transition also at the urban level [1, 2], but local policies might allow faster implementation and more efficient and locally relevant measures. At the time of the study, Nairobi has no local energy sector plans and policies in place, although Nairobi consumes over a half of all electricity generated in the country [12], and its energy needs and challenges differ from those of other counties in Kenya. The vertical integration across levels of governance was also considered weak.

While the national focus in the energy sector is on achieving universal electricity access in the country, urban areas face imminent challenges with the provision of services that are of higher priority than electricity, such as housing and water. There are no institutions in charge of specifically urban energy. Therefore, one of the major barriers to an urban energy transition is the lack of institutional capacity at the urban level. Efficient, systemic and integrated urban policies are generally difficult to design and implement, while local administrations often lack the legislative, financial and human capacity for implementing such effective policy approaches [1, 2, 9], which is also the case in Nairobi.

Siloed operation is typical for stakeholders of urban centers, which is associated with weak or disconnected institutional frameworks and fragmented urban governance [1, 21, 25]. Several interviewees had noted the disconnectedness in Nairobi between the city and county governance and key stakeholders in the energy sector. They also lamented that willingness of actors to collaborate and share information openly is low, while availability and reliability of information commonly hinders informed and systemic decisionmaking in emerging countries [25]. Lack of stakeholder involvement can lead to mismatched priorities and thus inefficient and uninformed outcomes in decisionmaking [27]. Additionally, the siloed operation of urban stakeholders inhibits integrated approaches to the provision of urban services, which could bring significant synergies and energy efficiency improvements [1].

The integration of urban policies, infrastructures and resource streams requires sustained cross-sectoral collaboration. Professional and industry associations currently act as important mediators that are able to bring actors and interest groups together. In addition to horizontal integration between various stakeholders of the urban energy system, vertical alignment between levels of governance is required for efficient and comprehensive energy policy approaches [21]. Coordinated dialogue and collaboration across levels of governance and between the urban stakeholders create ability to identify barriers and find solutions concerning urban energy transitions [2]. However, a current lack of long-term planning was noted. Among the various immediate needs, urban energy issues tend to be addressed in a reactive instead of a proactive manner.

High amount of government control and monopolies or near-monopolies in the energy sector tend to sustain and enforce policies and practices that protect the predominant regime [27], which creates resistance for change and hinders regime shifts. However, in Kenya private sector participation and the market entry of IPPs are increasingly enabled, and generation, transmission and distribution of electricity have been unbundled and partially privatised. A national utility representative expressed that they see private utilities and niche technologies as opportunities for collaboration, not as opposing competition. The significance of renewable energy and energy efficiency has also been acknowledged in policy outlines and national roadmaps, which indicates a strong support from national regime institutions. There were perceptions that the utility is guided by the primary concern of profit and thus the incentives to lower costs for the end users or to improve the reliability of the grid are insufficient. It is difficult to assess whether these perceptions are fact-based to some extent or whether they stem from a rooted lack of trust towards regime actors, which is discussed later among other socio-cultural barriers.

6.3.2 Financial and economic barriers

Financial barriers are a key issue for the adoption of renewable energy technologies in several countries that are economically resource-constrained [27]. In Kenya, financial hindrances have included lack of awareness on financing options, lack of access to affordable capital and low feed-in-tariffs, while power sector projects have received substantial funding from international development institutions and foreign governments. The amount of capital is no longer perceived an issue, but the access to it is. Limited possibilities for lending money or the lack of financial institutions and instruments providing access to capital are common barriers related to financing [26, 27], while poor access to financing, insufficient financing models and the high energy costs in Kenya have also been noted as hindrances before [36, 38, 41].

Technological niches are typically protected from main market competition by public subsidies and regulatory measures [17]. Several financing institutions and mechanisms dedicated for renewable energy and energy efficiency projects have been established in the recent years, but more innovative financing mechanisms were called for. High initial costs for both businesses and end users is a common hindrance for adopting new energy technologies especially in low-income countries [28]. The low income levels, high upfront costs, high cost of capital and low access to consumer credit guide the purchasing choices of users.

Power infrastructure projects generally require large investments, which hinders strenghtening the robustness of the distribution grid, while development funding is directed especially towards extending electricity access. Additionally, renewable energy projects in developing countries are commonly hindered by risks due to uncertainties in price developments of electricity [28], while the cost of power in Kenya has been volatile, and there are uncertainties of policy developments and the effects of climate change on the sector. Investors may also consider renewable energy projects unworthy investments due to low feed-in-tariffs.

The economical feasibility of power sector projects can be affected by national level policies, while the international development ecosystem has a large role in funding power sector projects. However, the projects and programmes driven by development funding may last for a short time and have limited resources compared to the goals they are targeted to achieve. Lack of understanding of the local context (socio-technical landscape) and similarly lack of involvement of local expertise may also cause inconveniences and overlaps in such projects. The issues of poor coordination and communication are also present in the development ecosystem and should be paid attention to in order to achieve efficient outcomes.

6.3.3 Market barriers

No major barriers specifically related to the operation of markets for renewable energy and energy efficiency technologies were identified. Lack of competition is a common market barrier for renewable energy and energy efficiency technologies especially when there are state-controlled monopolies in the energy sector [28], but in Kenya private sector participation and the entry of IPPs is increasingly encouraged in the energy sector. Although electricity transmission and distribution are typically natural monopolies based on a least-cost principle [28], in Kenya the regulatory environment allows e.g. mini-grid companies to operate as utilities. However, the utility virtually faces no competition, which was considered to cause a lack of incentives to improve the quality and reliability of the distribution infrastructure.

There are no trade barriers hindering the competitiveness of renewable energy technologies on the market, and the adoption of renewable energy is encouraged through tax exemptions and feed-in-tariffs, although the awareness of them is low. The issues associated with development-driven financing in the sector might cause inefficient market outcomes, as the development and donor funding directs heavy subsidies for technologies and projects that otherwise might not necessarily be among the most cost-efficient and viable options.

6.3.4 Technological barriers

The MLP suggests that the stabilisation of viable niche technologies depends on the level of their development. Niche technologies are generally ready to break through when the learning processes have stabilised in a dominant design, influential actors have joined the supporting groups, price/performance ratios have improved and the innovation is adopted by market niches. [16] The lack of one or several of these factors can be seen as a barrier for the adoption of a niche innovation.

The lack of standards and suppliers' uncompliance with them has been noted as a hindrance before [51], which the findings also support. Associations and regulatory agencies have worked to develop standardisation programmes in the sector, but the improvements in standard and label requirements for renewable energy and energy efficient technologies were not yet well visible. Quality issues also cause lack of trust in the technologies. For instance, solar PV products were imported to Kenya in large quantities during the past couple of decades, but the performance of the products used to be inadequate and they would fail sooner, i.e. the niche technologies were not well developed. The lack of social acceptance resulting from previous poor performance of earlier generation products now hinders the adoption of new technologies. Consumers tend to prefer low purchasing costs over low lifecycle costs [29], while the poor quality products are often the cheapest ones. Therefore, quality issues are also a question of consumer awareness. Energy systems are often sold without sufficient warranties or decommissioning, as there are no such requirements for businesses.

Lack of expertise and skilled personnel to operate and maintain energy systems is a common barrier to new energy technologies in developing countries [28], but several public and private sector education, training and certification programmes have been established in Nairobi. Developments in the sustainable energy domain enable significant opportunities for new businesses and jobs. Therefore, the availability of local expertise can be expected to increase in the near term.

Lack of required infrastructure has been identified as a hindrance for renewable energy development [27]. In Nairobi, lack of proper infrastructure and housing hinders access to electricity and other modern energy services in the slum areas, as it is not always technically possible to provide safe and formal electricity connections to informal settlements. While renewable energy projects are commonly hindered and delayed due to the lack of site specific information [28], efficient development of urban infrastructures and built environment in Nairobi suffers from low availability of information, since sufficient information is not publicly available or openly shared between various urban service providers. Low reliability of electricity supply is also an infrastructure-related barrier, as it implies the need for fossil-based backup power, whereas the reliability on variable hydropower prevents cutting down fossil fuels from the generation mix.

6.3.5 Socio-cultural barriers

Socio-cultural barriers can be associated with the broader landscape level of the socio-technical system. These factors are typically difficult to change, as rooted cultural norms, practices and values tend to change only slowly [16].

Awareness is an important precondition for wide-scale adoption of sustainable energy technologies. Low awareness of the benefits and opportunities of sustainable energy is among the main socio-cultural barriers to adoption of renewable energy and energy efficiency in Nairobi. As noted previously, the low public and instutional awareness of the various benefits of sustainable energy hinders the adoption of sustainable energy solutions [28, 51], which is affected by the poor availability of information for decisionmakers. Low awareness and availability of reliable information was well recognised by interviewees. However, in addition to academia, private sector players and international actors are increasingly contributing to generating and sharing new information.

Sustainability and energy efficiency awareness among the public is low. Especially low-income end users typically prefer low upfront costs over low operating costs in the long-term [29]. Therefore, communicating the potential cost savings and practical benefits of sustainable energy technologies should be emphasised in awareness creation instead of e.g. energy efficiency or emissions. Awareness of quality and correct use of products is also low among consumers. Due to the quality issues discussed earlier, awareness on quality and maintenance of energy products and systems is also needed. Awareness creation is considered difficult, since it requires sustained efforts. Among organisations and decisionmakers, increasing attention is paid to sustainability issues in energy as well as other sectors.

Promoting awareness and adequate communication can also increase social acceptance towards energy technologies, which may raise social, cultural and environmental concerns [28]. Awareness and availability of information will further reduce resistance towards change and support people in making informed decisions based on reliable information [29]. Social acceptance is not a major issue in Nairobi, as several interviewees pointed out that Nairobians are quick to adopt new technologies and there is increasing awareness and willingness to adopt sustainable solutions, partly driven by the already felt effects of climate change as a landscape-level pressure. Whereas in industrialised countries there is a certain taken-for-grantedness associated with electricity and other basic services, electricity and sufficient supply of it is still relatively new to Kenya. This might be among the reasons for the accommodating attitudes towards energy efficiency and conservation.

Lack of trust towards various parties involved in energy projects or towards information providers was mentioned in literature as a hindrance to energy efficiency investments [26]. The findings also indicate that lack of trust is a rooted behavioural factor in the socio-technical landscape. Interviewees expressed frustration and lack of trust towards public actors in the energy sector, with the exception of the regulatory agency that received positive feedback. There were claims that political interests, corruption and cartels are strong in the power sector and corruption and lack of trust embedded in societal mechanisms in general. It is difficult to estimate the extent to which the issues of distrust, corruption and lack of collaboration are caused or enforced by each other. It was noted that people were not well aware of activities of the public sector and that information of government projects is not publicly shared, which further reduces the trust in the public sector. However, such tensions in the predominant regime might open up windows of opportunity for new developments and novelties. Due to the frustration on the existing regime, high expectations are placed on private sector players and niche technologies that could reduce dependency on the predominant technologies such as the unreliable grid infrastructures and the high and volatile prices of grid electricity.

7 Conclusion

This chapter presents the summarised conclusions of the thesis after a comprehensive discussion and analysis presented in the previous chapter. The key findings of the study are summarised based on the research questions, followed by a brief discussion on the limitations of the study and suggestions for future research.

7.1 Summary of key findings

The purpose of this study was to identify the main urban energy challenges and the barriers hindering the transition to a sustainable urban energy system in Nairobi with a focus on the electricity sector. A literature review was conducted to understand the dynamics of urban energy transitions along with the associated challenges and barriers. Empirical data was collected mainly through semi-structured qualitative interviews to analyse the research themes in the context of the case study. The study met the research objectives and the findings were in accordance with previous literature for the most part.

The growth of global population and its energy demand is driven by emerging countries, which are rapidly urbanising. Therefore, the transition to sustainable energy in the urban areas of emerging markets is critical for the global efforts to mitigate climate change, while access to modern energy is also a critical enabler of socio-economic development. Over a half of all electricity generated in Kenya is consumed in Nairobi, where the urban population and its energy needs are increasing, whereas national efforts are steered towards the primary goal of achieving universal access to electricity. Although Nairobi is mostly covered by the national electricity grid and the generation mix is dominated by renewable sources, there are still several challenges and barriers related to the provision of clean, affordable and reliable energy in the city.

The study found that the main urban energy challenges in Nairobi are the reliability of electricity supply due to the inadequate and inefficient distribution infrastructure, provision of modern energy services for the urban low-income residents, and pollution, which mostly results from the use of unsustainable fuels in transportation, cooking and the use of diesel power generators. Additionally, the issue of e-waste associated with various energy products increasingly raises concerns in the absence of adequate recycling and maintenance practices.

The main barrier hindering the transition to sustainable energy is the insufficient institutional capacity at the urban level, which is associated with policy fragmentation, the absence of urban energy policies and inadequate coordination and communication between relevant stakeholders. Other main barriers hindering the transition to sustainable urban energy include lack of collaboration and trust between urban energy stakeholders, lack of suitable financing mechanisms and access to affordable capital, low awareness on the benefits and opportunities of renewable energy and energy efficiency and poor availability of relevant information. Recent developments have reduced the hindrances related to availability of skills and expertise as well as technical standards and compliance with them. The recent regulatory measures at the national level are perceived as major enablers for the wider adoption of renewable energy and energy efficiency solutions, especially after the new intended developments in national policy frameworks. However, the planned inclusion of coal in power generation capacity expansion programmes conflicts with Kenya's national and international commitments to sustainable development and can be considered another barrier for the sustainable energy transition at the national level.

7.2 Limitations of the study

The study was conducted as a case study of the city of Nairobi. Therefore, the results are restricted to one geographical area and cannot be straightforwardly generalised to other emerging countries.

Another limitation of the study is that the sampling of respondents was focused on the energy sector, whereas also the views of other stakeholders of the urban energy domain would be beneficial to gain a more holistic understanding on urban energy transitions, which are complex and cross-sectoral phenomena by nature. The limited size of the sample and short duration of the study in comparison to the long-term nature of socio-technical transitions can be considered another limitation implied by the scope and duration of the thesis project. However, the amount and quality of the collected data provided sufficient information to answer the research questions adequately in the scope of this study.

The interpretative nature of the qualitative case study methods and the resulting observer and participant biases may have limited the reliability of the results. These biases were minimised by systematic data collection and analysis procedures and data triangulation. Additionally, the accuracy and validity of the study was limited by the availability and quality of information used as secondary data.

7.3 Suggestions for future research

This study sheds light on the little researched topic of sustainable urban energy in emerging countries with a comprehensive case study that combines socio-technical and techno-economic approaches to urban energy transitions. Previous case studies found in the literature on urban energy transitions mainly focus on cities in industrialised economies. Few similar studies could be found from cities in emerging countries especially in SSA. Further research on the topic could increase understanding on how to overcome the urban energy challenges and provide modern energy services for increasing urban populations in Kenya and other emerging countries in a sustainable manner.

Several suggestions for future research can be drawn from the limitations of the study. The focus of the study was on the electricity sector, covering the generation, distribution and use of electricity in Nairobi. Since there are major urban energy challenges related to the unelectrified sectors of cooking and transportation in Nairobi, future studies could be conducted to assess possibilities and opportunities for sustainability transitions in these sectors.

Low availability of information was a limitation during the research process and also noted as one of the barriers in the results of the study. Especially accurate city-level energy data is scarce. New information could be generated to improve the availability of relevant statistics and numerical data to provide baselines for decisionmaking and demand-led energy planning concerning urban energy. Examples of possible topics include city-level energy use and demand, load profiles and energy use by sector.

Additionally, several interesting topics emerged that could not be addressed more in depth due to the limited scope and duration of the thesis research project. Further research could especially address questions related to the institutional capacity at the urban level and how it could be upgraded and leveraged to efficiently facilitate urban energy transitions.

References

[1] Grubler, A., Bai, X., Büttner, T., Dhakal, S., Fisk, D.J., Ichinose, T., Keirstead, J.E., Sammer, G. et al. *Chapter 18: Urban energy systems.* Global Energy Assessment: Toward a Sustainable Future. Eds. Team, GEA Writing, pp. 1307–1400, Cambridge University Press and IIASA, 2012.

[2] *Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems.* International Energy Agency (IEA), 2016. Available at: http://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2016_ExecutiveSummary_EnglishVersion.pdf [accessed 19.6.2018]

[3] *Global report on urban health: equitable, healthier cities for sustainable development.* World Health Organization (WHO), 2016. Available at: http://www.who.int/kobe_centre/measuring/urban-global-report/en/ [accessed 20.6.2018]

[4] *Energy and Climate Change.* World Energy Outlook Special Report, International Energy Agency (IEA), 2015. Available at: http://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf [accessed 21.6.2018]

[5] *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)].* Intergovernmental Panel on Climate Change (IPCC), Geneva, 2014.

[6] *Adoption of the Paris Agreement.* Report No. FCCC/CP/2015/L.9/Rev.1. United Nations Framework Convention on Climate Change (UNFCCC), 2015. Available at: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf [accessed 19.6.2018]

[7] *Renewable Energy and Energy Efficiency in Developing Countries: Contributions to Reducing Global Emissions.* United Nations Environment Programme (UNEP), 2017. Available at: http://www.unenvironment.org/resources/report/renewable-energy-and-energy-efficiency-developing-countries-contributions-0 [accessed 19.6.2018]

[8] *Transforming our world: The 2030 Agenda for Sustainable Development.* UN General Assembly, 21 October 2015, A/RES/70/1. Available at: http://www.refworld.org/docid/57b6e3e44.html [accessed 19.6.2018]

[9] Silver, J. and Marvin, S., *Powering sub-Saharan Africa's urban revolution: An energy transitions approach.* Urban Studies, vol. 54, no 4, pp. 847–861, 2016.

[10] *African Energy Outlook: A Focus on Energy Prospects in Sub-Saharan Africa.* International Energy Agency, 2014.

[11] Parnell, S. and Walawege, R., *Sub-Saharan African urbanisation and global environmental change.* Global Environmental Change, 2011.

[12] *Updated Least-Cost Power Development Plan. Study period: 2011–2031.* Republic of Kenya, Ministry of Energy, 2011.

[13] *Report of the World Commission on Environment and Development*, United Nations General Assembly, 96th plenary meeting, 11 December 1987, Document A/RES/42/187, UN, 1987.

[14] *World Development Indicators 2017.* World Bank, Washington DC, 2017.

[15] Geels, F., *Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study.* Research Policy 31, pp. 1257–1274, Elsevier, 2002.

[16] Geels, F. W., and Schot, J., *Typology of sociotechnical transition pathways.* Research policy, vol. 36, no. 3, pp. 399–417, 2007.

[17] Twomey, P., and Gaziulusoy, A. I. *Review of System Innovation and Transitions Theories: Concepts and frameworks for understanding and enabling transitions to a low carbon built environment.* Visions and Pathways project, Melbourne, Australia, 2014.

[18] Dong, L. and Mori, A., *Multi-Level Analysis of Sustainable Energy Transition in Kenya: Role of Exogenous Actors.* International Journal of Energy Economics and Policy, vol. 7, no 5, pp. 111–122, 2017.

[19] Rohracher, H. and Späth, P., *The Interplay of Urban Energy Policy and Socio-technical Transitions: The Eco-cities of Graz and Freiburg in Retrospect.* Urban Studies, vol. 51, no 7, pp. 1415–1431, 2014.

[20] Verbong, G. and Geels, F., *The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system.* Energy Policy, vol. 35, pp. 1025–1037, 2007.

[21] Walker, R.V., Poponi, D. and Lefevre, B. *Advancing Toward a more Sustainable Urban Energy System: Policy and Technology Considerations.* World Resources Institute & International Energy Agency, 2015.

[22] Rutherford, J. and Coutard, O., *Urban energy transitions: Places, processes and politics of socio-technical change.* Urban Studies, vol. 51, no 7, pp. 1353-–1377, 2014.

[23] Carreon, J.R. and Worrell, E., *Urban energy systems within the transition to sustainable development. A research agenda for urban metabolism.* Resources, Conservation and Recycling, vol. 132, pp. 258–266, 2018.

[24] *Key world energy statistics.* International Energy Agency, 2017.

[25] Bai, X., Surveyer, A., Elmqvist, T., Gatzweiler, F. W., Güneralp, B., Parnell, S. et al. *Defining and advancing a systems approach for sustainable cities.* Current opinion in environmental sustainability, vol. 23, pp. 69–78, 2016.

[26] Thollander, P., Palm, J. and Rohdin, P., *Categorizing Barriers to Energy Efficiency: An Interdisciplinary Perspective.* Energy Efficiency, InTech, 2010.

[27] Painuly, J.P., *Barriers to renewable energy penetration; a framework for analysis.*, Renewable Energy, vol. 24, no 1, pp. 73–89, Elsevier, 2001.

[28] Sena, S. and Ganguly, S., *Opportunities, barriers and issues with renewable energy development – A discussion.* Renewable and Sustainable Energy Reviews, 69, pp. 1170–1181, Elsevier, 2017.

[29] Reddy, S. and Painuly, J.P., *Diffusion of renewable energy technologies — barriers and stakeholders' perspectives.* Renewable Energy, vol. 29, no 9, pp. 1431–1447, Elsevier, 2004.

[30] Zainal, Z., *Case study as a research method.* Jurnal Kemanusiaan, vol. 5, no 1, 2017.

[31] Yin, R.K., *Case study research: Design and Methods.* 3rd ed., Applied Social Research Method Series, vol. 5, 2003.

[32] Saunders, M., Lewis, P. and Thornhill, A., *Research methods for business students.* 5th ed., Pearson, 2009.

[33] Silverman, D., *Doing qualitative research: A Practical Handbook.* 2nd ed. Sage Publications, 2005.

[34] *Final Report. Part II: The Master Plan.* The Project on Integrated Urban Development Master Plan for the City of Nairobi in the Republic of Kenya, Nairobi City County (NCC) and Japan International Cooperation Agency (JICA), Nippon Koei, December 2014.

[35] *World Economic Outlook.* International Monetary Fund, 2017.

[36] *African Economic Outlook 2017: Entrepreneurship and Industrialisation.* African Development Bank, Organisation for Economic Co-operation and Development and United Nations Development Programme, 2017.

[37] *The Global Competitiveness Report 2017–2018.* World Economic Forum, 2017.

[38] *Kenya Vision 2030: The Popular Version.* Government of the Republic of Kenya, 2007.

[39] *Situational Analysis of Energy Industry, Policy and Strategy for Kenya.* Institute of Economic Affairs, 2015.

[40] *Grid Development and Maintenance Plan 2016-17 – 2020-21.* Kenya Power. Available at: http://kplc.co.ke/img/full/4GbgxauuUnXZ_GRID%20DEVELOPMENT%20final%202016.pdf [accessed 28.3.2018]

[41] *Development of Kenya's power sector 2015–2020.* Power Africa, USAID Kenya and East Africa, May 2016. Available at: http://www.usaid.gov/sites/default/files/documents/1860/Kenya_Power_Sector_report.pdf [accessed 19.6.2018]

[42] *KenGen Power Plant Locations.* KenGen. http://www.kengen.co.ke/contact [accessed 12.3.2018]

[43] *Electricity cost in Kenya.* Regulus Limited. http://stima.regulusweb.com/ [accessed 13.8.2018]

[44] *Schedule of Tariffs – 2018.* Kenya Power. Available at: http://www.kplc.co.ke/content/item/691/electricity-cost-tariffs---schedule-of-tariffs-2018 [accessed 13.8.2018]

[45] *Distribution Master Plan Study. Final Report. Volume I.* Prepared for The Kenya Power & Lighting Company Limited by Parsons Brinckerhoff, April 2013. Available at: http://renewableenergy.go.ke/index.php/content/19 [accessed 28.6.2018]

[46] *Map of Transmission Lines and Substations.* Kenya Electricity Transmission Co. Ltd. http://www.ketraco.co.ke/ [accessed 21.2.2018]

[47] *The State Department of Energy.* Ministry of Energy and Petroleum, http://energy.go.ke/energy/ [accessed 13.2.2018]

[48] Tigabu, A. et al., *Capability development and collaboration for Kenya's solar and wind technologies: analysis of major energy policy frameworks.* Innovation and Renewable Energies in Kenya (IREK), 2017.

[49] *The Energy Solar Water Heating Regulations 2012.* Republic of Kenya, Ministry of Energy, 2012. Available at: http://renewableenergy.go.ke/index.php/content/19 [accessed 29.6.2018]

[50] *President Kenyatta encourages more private sector investment in power projects.* News release, Official Website of the President, 30.1.2018, http://www.president.go.ke/2018/01/30/president-kenyatta-encourages-more-private-sector-investment-in-power-projects/ [accessed 13.2.2018]

[51] *Renewable Energy.* Kenya Climate Innovation Center, http://www.kenyacic.org/sectors/renewable-energy [accessed 13.2.2018]

[52] *Kenya's Popular Version of the New Urban Agenda: Towards Inclusive, Safe, Resilient and Sustainable Cities and Human Settlements.* Ministry of Transport, Infrastructure, Housing and Urban Development, Nairobi, Kenya, 2017.

A List of interviewed organisations

Representatives of the following organisations were interviewed for this study:

Africa Enterprise Challenge Fund: Renewable Energy and Adaptation to Climate Technologies (development financing institution)

African Climate Change Fellowship Program (research programme)

African Energy Policy Research Network (non-governmental organisation)

The Association of Energy Professionals Eastern Africa (industry association)

EED Advisory Ltd (private company)

Eenovators Ltd (private company)

GoGreen Energy Ltd (private company)

Kenya Association of Manufacturers: Centre for Energy Efficiency and Conservation (industry association)

Kenya Climate Innovation Center (business incubator)

Kenya Green Building Society (industry association)

Kenya Power (national electricity utility)

Kenya Renewable Energy Association (industry association)

Kenyatta University (university)

Strathmore Energy Research Centre (research institution)

UN-Habitat: Urban Energy Unit (intergovernmental development organisation)