Bridging the Urban Energy Divide: Equity-Focused Transition Pathways for Sub-Saharan African Cities

by

Joel Yongoua Nana

Thesis presented for the degree of DOCTOR OF PHILOSOPHY

Faculty of Engineering & the Built Environment

Department of Chemical Engineering

UNIVERSITY OF CAPE TOWN

Supervisor: Prof. Harald Winkler (PRISM, School of Economics, UCT)

Co-supervisor: Prof. Harro von Blottnitz (Department of Chemical Engineering, UCT)

20 May 2025

Declaration

I hereby declare that the entirety of the work contained herein, represents my own work, I am the sole author of this work, and that this work has not in part or entirety been previously submitted to this or any other institution for obtaining any qualification.

I have equally read the current University ethics regulations and accede responsibility for any issues that may be raised from this study. I have endeavoured to identify all the potential risks linked with this research likely to emanate while conducting this research, obtained ethical clearance and recognize my obligations.

Preface

Some of the text included in this thesis, or alternative versions of it, has already been published or is in the process of being published, as outlined below:

- Parts of Chapter 4: Energy use, GHG emissions and Inequalities in sub-Saharan African cities has been published as a conference paper (Yongoua Nana, Winkler and Von Blottnitz, 2022) at the 2022 IEEE Power Africa Conference
- Parts of Chapter 4: Energy use, GHG emissions and Inequalities in sub-Saharan African cities has been accepted and is currently in the process of being published as a book chapter by Yongoua Nana, Cilliers and Borchers (forthcoming) in an edited volume, entitled Urban Energy Transition, 3rd Edition: Rise of Regeneration - Cities and Regions for a Stable Climate (Droege et al., forthcoming)
- Some of the material included in Chapter 4: Energy use, GHG emissions and Inequalities in sub-Saharan African cities, has contributed to a report entitled “Renewables in Cities 2021 Global Status Report” produced by REN21 - Renewable Energy Policy Network for the 21st Century
- Some of the material from the scenario conceptualisation in Chapter 6: Modelling Alternative Pathways to a Just Urban Energy Transition, has contributed to a journal article (Yongoua Nana and Dioha, 2024) published in Environmental Research Letters

See also positionality of the author in section 1.4

Abstract

This thesis examines how alternative urban energy transition pathways in Sub-Saharan Africa could simultaneously address the imperatives of equitable energy access and use across different income groups, while meeting other development and sustainability goals. Through detailed analysis of six cities - ranging from metropolitan centres to smaller towns - the research provides new insights into the patterns and drivers of energy inequalities in African urban contexts.

The study makes several contributions to knowledge. First, it presents the first comprehensive, multi-city analysis of urban energy consumption and emissions across key economic sectors in African cities. Key findings highlight that urban energy profiles in Sub-Saharan Africa exhibit far greater heterogeneity than often recognized. Results from the scenario analysis also showed that this heterogeneity results in varied equity outcomes even when the study cities were subjected to the same policy interventions, therefore demanding more context-specific approaches to urban energy policy design. The research also identifies electricity use as uniquely significant among energy carriers, showing both the strongest correlation with GDP and typically the most unevenly distributed across household quintiles.

Second, the thesis makes relevant methodological contributions through the development and implementation of the Urban Household Energy Model (UHEM), a transparent bottom-up modelling framework custom-designed to analyse household energy inequalities in African urban contexts. Through extended application of the Gini coefficient and Lorenz curve to previously inaccessible municipal datasets, the research provides new evidence that household energy use inequalities consistently show significantly lower magnitudes than income inequalities, suggesting that energy's status as a fundamental need creates a "floor effect" in consumption patterns. This, however, does not extend to electricity use, which shows markedly higher inequalities, in some cases even exceeding income inequality.

Third, the research advances both scholarly understanding and practical policy development through its assessment of energy transition policies. Analysis of current policy commitments (Stated Energy Policies Scenario - STEPS) reveals that despite often lacking clearly actionable measures on equity, these interventions could achieve meaningful reductions in household energy use inequalities, with clean cooking and electricity access interventions typically the most powerful levers for reducing household energy inequalities. The research further examines two alternative scenarios - Blues and Harmony - specifically designed through an equity lens. The Blues scenario, emphasizing bottom-up, community-driven approaches, demonstrated more significant outcomes across most metrics, achieving substantially greater reductions in household energy use inequality than STEPS and Harmony across several study cities. However, the findings have revealed a non-linear relationship between clean energy access and inequality reduction, suggesting diminishing returns beyond certain thresholds of clean energy adoption in advancing equity goals. Additionally, analysis of hypothetical income redistribution policies suggests their potential complementary role in reducing energy inequalities, achieving higher outcomes to energy-focused policies alone in some of the studied cities.

These findings have important implications for urban energy policy design in Africa. While current stated policies show promise in reducing overall energy and emissions inequalities, achieving more equitable outcomes would benefit from: (1) decentralizing energy access and governance and enabling regulatory frameworks, (2) building local research expertise and data infrastructure

to support context-specific planning, (3) enabling economic equity through policies that encourage community wealth creation and local ownership of energy assets, and (4) strengthening municipal authority while fostering strategic coalitions across governance levels.

Acknowledgments

This thesis would not have been possible without the support, guidance, and encouragement of many individuals to whom I am deeply grateful.

First and foremost, I extend my sincere gratitude to my supervisors, Prof. Harald Winkler and Prof. Harro von Blottnitz. Their patient mentoring, critical insights, and thoughtful guidance have been instrumental in shaping both this document and my development as a researcher. Their ability to challenge my thinking while providing constructive direction has greatly enhanced the quality and rigor of this work.

I am profoundly thankful to my wife, Malaika, whose unwavering support and understanding made this journey possible. Her patience when I had to prioritize research over family time, her words of encouragement during challenging periods, and her steadfast belief in me were crucial in helping me persevere through this process.

I would like to acknowledge my colleagues at Sustainable Energy Africa who created a supportive and flexible work environment that allowed me to balance full-time employment with my studies. Their understanding and support were invaluable in helping me balance these dual commitments.

Special thanks go to my colleagues at the Energy for Growth Hub - Rose, Michael, and Mark - whose intellectual engagement and fresh perspectives consistently challenged my thinking and enriched my research. Their insights helped broaden the scope and impact of this work.

I am also deeply grateful to the cities of Cape Town, Dakar, Nairobi, Yaoundé, Kasese, and Tsévié for entrusting me with their data and allowing its use to advance our collective understanding of urban energy transitions. Their willingness to share information and collaborate in this research has been essential in generating new insights that I hope will benefit other cities across Africa.

Above all, I give thanks to God Almighty for being my rock and compass.

Contents

List of Figures

List of Tables

List of abbreviations

C40	C40 City Leadership Group
CAP	Climate Action Plan
CoMSSA	Covenant of Mayors in Sub-Saharan Africa
DINA	Distributional National Accounts
DG	Distributed Generation
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IR PAM	Income Redistribution Policy and Measure
LCU	Local Currency Unit
LEAP	Low Emissions Analysis Platform
LPG	Liquefied Petroleum Gas
MEM	Modern Energy Minimum
MTF	Multi-Tier Framework
NDC	Nationally Determined Contributions
OPHI	Oxford Poverty & Human Development Initiative
PAM	Policy and Measure
PPP	Purchasing Power Parity
SAMSET	Supporting African Municipalities in Sustainable Energy Transitions
SAIDI	System Average Interruption Duration Index
SEACAP	Sustainable Energy Access and Climate Action Plan
SI	Supplementary Information
SSA	Sub-Saharan Africa
STEPS	Stated Energy Policies Scenario
UHEM	Urban Household Energy Model
UNDP	United Nations Development Programme
WID	World Inequality Database

Chapter 1 : Introduction

Cities run on energy, with their pivotal role in shaping global energy trends tracing back to the Industrial Revolution. Today, they account for nearly 75% of global energy consumption and 70% of global CO_2 emissions – all while generating 80% of global gross domestic product - GDP (IEA, 2021). This central role of cities is only set to grow. Over half of the world's population now lives in urban areas, and this figure is expected to rise to about 70% by 2050 (Figure 1), driven by rapid urbanization, particularly in lower-income countries where youth populations are large and economic opportunities are increasingly concentrated (IEA, 2024b).

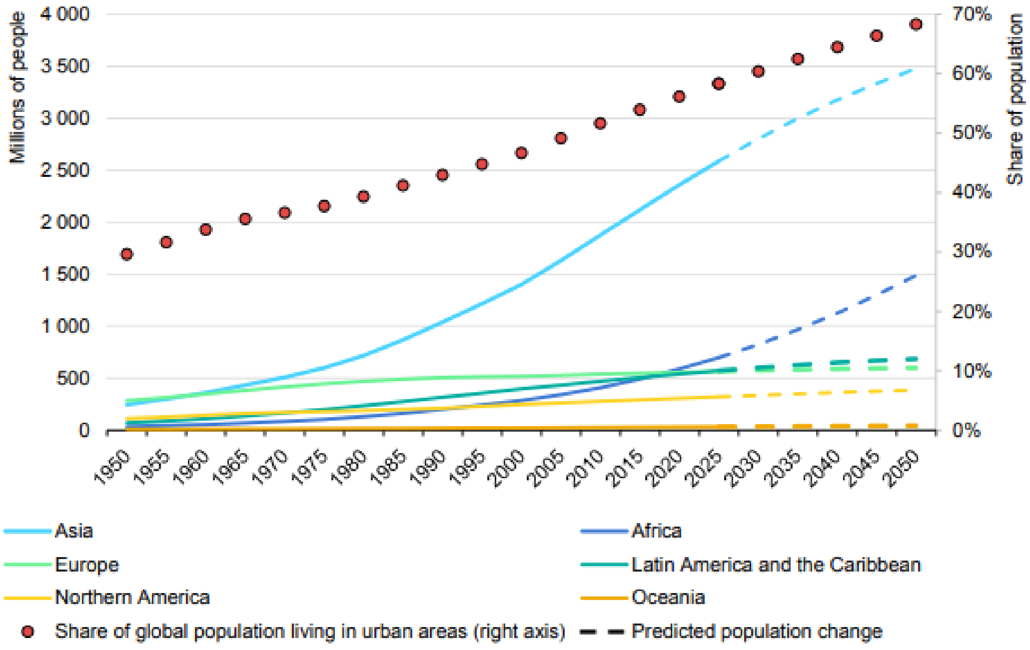


Figure 1. Historical and projected urban population by region, 1950-2050.
Source: (IEA, 2024b).

With this shift comes both immense challenges and opportunities. On the one hand, cities are at the frontline of urgent climate action, and on the other, they hold the greatest potential for reducing emissions. The Coalition for Urban Transitions (2019) found that concerted measures focused on urban infrastructure, buildings, transport, and waste could cut city emissions by nearly 90% by 2050 compared to a business-as-usual scenario. Moreover, other studies suggest that investing in urban clean energy solutions can deliver the highest return on carbon mitigation while fostering inclusive economic growth (Gouldson *et al.*, 2015; Estrada, Botzen and Tol, 2017; IEA, 2021). For instance, in sub-Saharan Africa, the cost of providing infrastructure in dense urban settings (USD 325 per person) is substantially lower than in remote rural areas (USD 2 387 per person), illustrating the efficiency gains possible in well-planned cities. Indeed, climate-positive investments equivalent to about 2% of global GDP (USD 1.83 trillion annually) in the 2020s could generate savings approaching USD 2.8 trillion by 2030 and USD 7 trillion by mid-century, in addition to supporting tens of millions of new jobs (Coalition for Urban Transitions, 2019).

These dynamics – rapid urbanisation, economies of scale, innovation hubs, and concentrated resource efficiency – place cities at the heart of the global energy transition, making them a decisive focus for research and action aimed at shaping a sustainable energy future. However, African cities represent a critical frontier, particularly when equitable outcomes in the global energy transition are a key objective.

1.1. Problem statement

African cities stand at a precarious intersection of rapid population growth, intensifying climate risks, and pervasive inequalities on energy access and use. With an estimated population of 1.2 billion people, Sub Saharan Africa (SSA) is home to some of the fastest-growing urban centres in the world (UNDESA, 2024). The region's urban population is believed to have increased more than sixteen-fold between 1950 and 2018, and urban population growth rates expected to remain at or above 3% per year through 2040 (United Nations, 2018a). By the end of the century, many African cities are anticipated to join the ranks of the world's megacities (Makinde, 2012; Slavova and Okwechime, 2016). Consequently, this rapid urbanization is set to be a significant driver of energy demand, and even faster in urban centres, where modelling shows that SSA urban energy demand could grow fourfold by 2040 (SEA, 2015b).

The economic role of SSA cities is further underscored in that only 143 cities are estimated to generate alone a combined $ 0.5 trillion or 50 percent of the region's GDP (Saghir and Santoro, 2018). With energy required to sustain these economic engines, African cities are well placed to inform how it is provided and consumed, although energy governance most often falls outside the purview of SSA municipal governments. In a context of a rapidly growing urbanization and a constantly evolving urban form, municipal governments – through careful planning – can play a critical role in addressing energy poverty and expanding sustainable energy access with profound positive impacts on social inclusion. This is further emphasized in the decision adopting the Paris Agreement which also recognizes the significant role of non-Party stakeholders, including cities, in addressing the global climate crisis.

By 2050, an estimated 60-70% of Africa's population is expected to reside in urban areas – many of which are already highly vulnerable to climate shocks such as floods, droughts, and heatwaves. This vulnerability is compounded by inadequate infrastructure, with around 600 million people still lacking access to electricity and close to 970 million relying on traditional biomass for cooking across the continent (IEA, 2022a). Such conditions disproportionately affect low-income households in informal settlements, amplifying inequities in both climate exposure and energy use. Further, despite contributing only about 4% of global greenhouse (GHG) gas emissions, no less than 70% of African cities are highly vulnerable to climate shocks. This vulnerability is expected to drive significant demographic shifts, with projections suggesting up to 86 million internal climate migrants in SSA by 2050 (Clement *et al.*, 2021).

Local governments are increasingly pressured to act, as seen in initiatives like the Covenant of Mayors in Sub-Saharan Africa (CoMSSA) and the C40 Cities[1] Climate Action Planning Africa Programme (C40, 2021; CoMSSA, 2024b). For example, as of September 2024, 382 SSA municipal governments had joined the CoMSSA, voluntarily committing to implementing climate and energy actions in their communities, while the C40 CAP Africa Programme, brings together 11 of SSA's largest cities that have pledged to become net-zero carbon by 2050. These commitments have generally culminated to the development of city-level climate action plans

---

[1] C40 Cities is a global network of nearly 100 mayors of the world's leading cities that are united in action to confront the climate crisis.

(CAPs) or energy strategies, charting municipal government's roadmaps towards locally driven clean energy transitions.

Yet, most CAPs face significant implementation challenges that stem from three interrelated constraints. First, insufficient data and limited technical capacity severely hamper evidence-based planning at the urban level. Whist energy and climate action planning will benefit greatly from an evidence-based situational analysis, it is largely acknowledged among energy practitioners that the continent still suffers critical lack of granular energy data access and availability (Avila *et al.*, 2017; Ouedraogo, 2017). The lack of data is even more apparent at city-level where often municipalities are far less resourced than their national governments to take up such monitoring and research (SEA, 2015a; Akrofi and Okitasari, 2022). While there is ongoing work to support urban-focused data creation and modelling efforts, they are still not enough. The scale of need far exceeds current capacity for providing customized technical assistance to thousands of SSA cities requiring data and planning support.

Second, existing CAPs demonstrate significant blind spots regarding the energy requirements for economic development. While there exists a well-documented correlation between energy consumption and economic growth, as reviewed in section 2.1, current planning frameworks fail to adequately address the need for energy-intensive urban development beyond basic household electrification and clean energy access. For instance, while cities must report on basic indicators like electricity access rates and emissions reduction targets to international platforms like CDP (CDP, 2024) and CoM SSA, crucial economic indicators such as industrial energy intensity, commercial sector consumption patterns, and other urban productivity metrics are notably absent. This narrow focus risks creating an artificial ceiling on urban energy aspirations, potentially constraining economic development opportunities.

Furthermore, a preliminary review of existing CAPs – detailed in section 2.3 demonstrates inadequate consideration of energy inequalities and their relationship to broader socioeconomic disparities. Current planning approaches often uncritically adopt technology-driven solutions developed in Northern contexts, without sufficient consideration of local socioeconomic conditions. These risks entrenching socio-economic inequalities when wealthier households are first to benefit from clean energy technologies, leaving vulnerable communities further behind.

The convergence of challenges – rapid urbanization, development imperatives, energy access challenges, equity considerations and implementation constraints – makes African cities uniquely important laboratories for understanding and implementing equitable energy transitions pathways. Their experiences offer critical insights for both theory and practice in navigating the complex intersections of energy access and use, economic development, and social equity in urban contexts globally. Addressing these challenges are well beyond the scope of a single thesis. This research therefore approaches this wicked problem by developing and analysing alternative transition pathways that explicitly consider both the indicators for supporting sustainable development and the distributional impacts across different socioeconomic groups, providing a foundation for more equitable urban energy planning.

1.2. Thesis objectives and research questions

Reflecting on the problem statement in section 1.1, a central research question for this thesis is identified:

How can alternative energy transition pathways in Sub-Saharan African cities address the disparities in energy access, use, and GHG emissions across different income groups while supporting urban development needs?

At the core of answering this question lies the need to bring the spotlight on the urban dimension of energy use and GHG emissions inequalities and provide analytical evidence whether existing local strategies, policies, or plans for clean energy transition are effectively addressing development priorities in a fair and equitable manner that reduces inequalities.

To this effect, we formulate the following sub questions in order to answer the overall research question above:

1. How do cities in SSA consume energy, and what are the key drivers of urban energy demand?
2. What is the status quo of household energy use and GHG emissions inequalities?
3. What evidence suggests whether existing local strategies, policies, or plans for clean energy transition are effective or not in addressing development priorities in a fair and equitable manner that reduces inequalities?
4. How can alternative pathways, beyond those stated in existing plans, contribute to energy access and stimulate urban economic development, while ensuring that local energy transitions promote equity in urban contexts?

Addressing the first sub-question will provide a picture of where and how energy is used in the studied cities across various key sectors in their respective base years and how these compare to international benchmarks for sustainable development. Further, the second sub question will add to this picture a novel look at energy use and emissions inequalities across household income groups in each study city. These sub questions, both examined in Chapter 4, will create the evidence-base to support the framing of the second part of the research.

The third sub-question (examined in Chapter 5) will qualitatively and quantitatively assess existing cities' energy and climate strategies and policies against a set of carefully identified energy sustainability indicators with the overall objective to establish whether the stated policy interventions effectively address inequalities in energy use and emissions. These indicators will include household energy use for each income group and corresponding fuel mix (GJ/year/HH); energy use per unit of GDP (GJ/US dollar); energy use per capita (GJ/capita); share of electricity in the energy mix; Gini coefficient of household energy use among several others.

The last sub-question (examined in Chapter 6) investigates measures or pathways beyond those stipulated in the current local energy and climate strategies, which will aim to achieve more ambitious energy equity targets. Similarly, these additional measures will be assessed against the set of sustainability indicators in terms of their effectiveness to address several development indicators as well as reducing energy and emissions inequalities.

Chapter 7 then revisits the overall research question through an extended discussion of the evidence presented in the thesis.

1.3. Outline of thesis

The thesis is structured as follows. Having introduced a problem statement, thesis objectives and research questions in the present chapter, Chapter 2 presents the literature review. This chapter provides a critical review of existing scholarship on the role of energy in driving local economic development, particularly in the context of SSA. It identifies key debates surrounding justice, equity, and energy distribution, and explores how these themes are addressed in current local energy and climate action planning. Special attention is given to the extent to which these strategies incorporate equity. Additionally, this chapter elaborates on essential concepts such as energy justice, democracy, equity, and inequality. It concludes by identifying notable gaps in the literature and current practices, positioning the thesis' contribution within the broader academic discourse.

Chapter 3 introduces the modelling and analytical framework employed in the thesis, beginning with a focus on six SSA cities that serve as case studies. It then outlines the modelling approach, emphasizing the Low Emissions Analysis Platform (LEAP) framework, particularly the demand modules and their mathematical formulation. The chapter also presents the custom-built Urban Household Energy Model (UHEM) for the purpose of this study, detailing the model flow, tree structure, and the disaggregation of energy demand. A comprehensive overview of the datasets for each city is provided, including the assumptions used to address data gaps and the methodologies applied for the various calculations.

Chapter 4 sets the scene. It establishes the energy use and emissions profiles for the six selected SSA cities in their respective base years, analysed across a range of sectoral indicators. It also delivers a quantitative assessment of the inequalities in energy consumption and emissions among households in these urban centres, offering a detailed picture of energy access and usage across different socioeconomic groups.

Chapter 5 examines the potential effects of stated policies and measures (STEPS) outlined in the existing energy strategies and climate action plans of the six cities under study. It assesses whether these STEPS are adequately aligned with development priorities and whether they promote equity in energy use across different household quintiles, as measured by the Gini coefficients and other indicators of energy poverty and clean energy access.

Chapter 6 presents two alternative energy pathways – Blues (bottom-up community-led) and Harmony (top-down city-led) – developed through a lens of equity and assesses their effects on energy and emissions inequality indicators. This chapter also explores how targeted income redistribution policy interventions compare with STEPS, Blues and Harmony in reducing energy and emissions inequalities.

Chapter 7 provides an integrated discussion of the key findings from the thesis, exploring their broader implications beyond the quantitative analysis. The chapter concludes with a comprehensive analysis of the policy implications for both local and national governments, offering actionable insights for urban energy transition strategies with equity as a key consideration. The chapter also identifies potential areas for future research.

Chapter 8 concludes by summarising the key features of the study and articulates the main contributions that the study makes to the field of urban energy transition and practice.

1.4. Positionality of the Author

Research is inherently shaped by the researcher's position, experiences, and relationship to the subject matter. It is therefore important to be transparent about the author's involvement with urban energy transitions in Africa, which preceded and informed this research. The contribution to knowledge is central to a PhD, and the author’s contribution is outlined at the end of the thesis in section 8.3. The positionality of the author and his contribution should be understood together.

From 2017 to 2020, the author served as a technical advisor for the Covenant of Mayors in Sub-Saharan Africa – CoMSSA – initiative (CoMSSA, 2024), working directly with municipal staff and civil society organizations in several of the cities studied in this thesis, particularly Yaoundé, Tsévié, and Dakar. This role involved developing technical requirements for data collection, providing capacity building support, and contributing to the final sign-off of questionnaires used for field data collection. This engagement provided unique insights into the challenges and opportunities of urban energy planning in African contexts, while also granting access to previously unavailable datasets that form a core analytical foundation for this research.

The author's involvement in data collection and climate action planning took different forms across the study cities, described in more detailed in section 3.6.1. In Yaoundé and Tsévié, the work involved collaborating with local consultants to conduct primary data collection through field surveys. This process not only generated valuable data but also helped build local capacity for energy planning. In Dakar, the role focused more on collating and analysing existing datasets, while for other cities like Cape Town, and Nairobi, the engagement was more indirect, primarily involving analysis and augmenting of the original dataset.

This positioning aligns with the principles of knowledge co-production, moving away from purely "expert-built" analytical frameworks to approaches that better capture local knowledge and management practices (Djenontin and Meadow, 2018). As Pettigrew, Woodman and Cameron (2001) argue, such deep engagement between academics and practitioners can produce knowledge that meets both the rigorous standards of academic research and the practical needs of urban planning. The author’s contribution is identified under each city’s data description in 3.6.1, in the first paragraphs for each city. In this way, the individual contribution as required for a PhD is clearly stated, while also making transparent the interaction with others.

Furthermore, this close involvement with the subject matter also requires careful consideration of potential biases. Throughout the research process, steps were taken to maintain awareness of how prior engagement might influence analysis and interpretation of results. To mitigate potential biases, the following measures were implemented:

- Maintenance of clear boundaries between practitioner and researcher roles
- Application of rigorous methodological approaches to data analysis
- Engagement with critical perspectives in the literature
- Solicitation of feedback from colleagues not involved in the original projects.

This positioning has both enabled and constrained the research in various ways. While it provided unique access to data and insights, it also required careful navigation of existing relationships and institutional dynamics. Nevertheless, this deep engagement with the practical realities of urban energy planning has enriched the research, allowing for insights that might not have been possible through more detached forms of inquiry.

The methodological choices, analytical framework, and interpretations presented in this thesis should therefore be understood within this context of engaged scholarship, where theoretical understanding is informed by, and hopefully informative for, practical action toward more equitable urban energy futures.

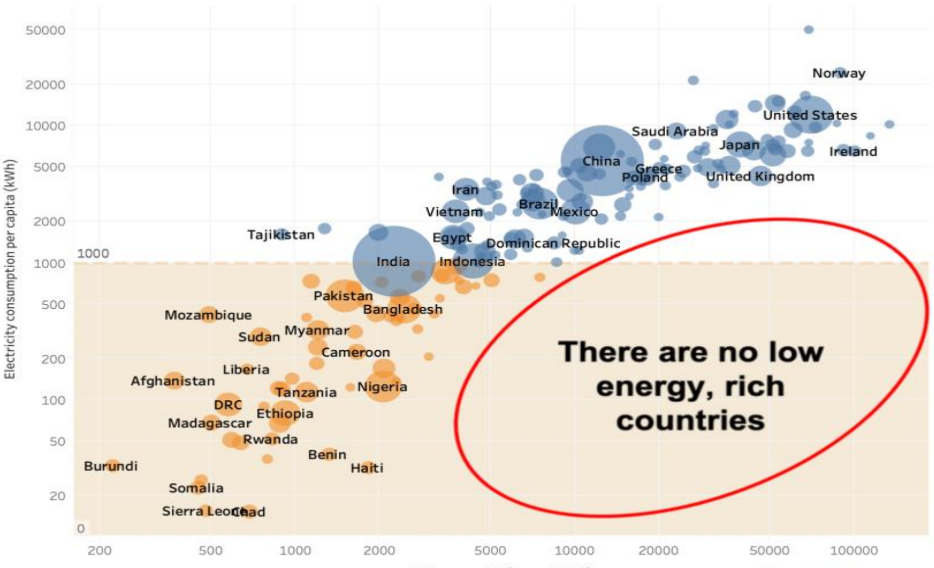
Building on the key motivations, research questions, and scope laid out in this chapter, the next chapter will delve deeper into the conceptual underpinnings and existing body of work that inform this research. By examining and critiquing the relevant literature, Chapter 2 provides the essential theoretical groundwork upon which the subsequent methodology and analyses are built.

Chapter 2 : Literature Review

Building on the problem statement and research motivations laid in Chapter 1, which highlighted the need for more evidenced-based urban climate action planning in SSA that both supports cities' development needs while addressing energy use inequalities, this chapter reviews several interconnected bodies of literature to frame the study's analytical approach. Section 2.1 begins by examining the role of energy as a driver of economic growth, with a focus on developing urban contexts. Section 2.2 then explores how inequalities in SSA – particularly those related to income and access – intersect with broader energy disparities. Moving to policy considerations, Section 2.3 looks at how cities across the region are integrating equity into their climate and energy strategies. Section 2.4 identifies key gaps in our current understanding of sustainable urban development pathways, energy profiling, and inequality analysis. Section 2.5 critically reviews current approaches to scenario design, particularly for subnational energy analysis. Section 2.5 introduces the theoretical framework that will guide the thesis, defining core concepts around energy justice, equity and inequality while outlining methods for quantifying inequalities. Lastly, Section 2.7 articulates the thesis's potential contributions to both scholarship and practice, detailing how this research fills identified gaps and offers new perspectives for advancing equitable energy transitions.

2.1. Energy as a driver of economic growth

There are no low energy, rich countries - Figure 2. Yet, today, there are still 3.8 billion people across 72 countries – more than half of them in Africa – living with insufficient electricity to access modern opportunity and prosperity (Rockefeller Foundation, 2024). In an era marked by rapid technological advancements and growing concerns over climate change, the issue of energy equity has never been more pressing. Access to reliable, affordable, and clean electricity is not just a matter of convenience; it is a fundamental human right and a key driver of economic development, education, and health care. Yet, for millions of people worldwide, particularly those in marginalized communities, this basic necessity remains out of reach. A recent study by Hirmer et al., (2024) suggests that nearly half of the reported progress in electrification over the last decade may be overstated, due to inconsistencies in data and methodological discrepancies regarding what qualifies as energy access.



Source: US Energy Information Administration, World Bank (2021)
$R^2 = 0.8$

ENERGY FOR GROWTH HUB

Figure 2. Electricity consumption vs GDP per capita, 2021.
Image source from (Todd Moss and Jacob Kincer, 2023)

Over the past 50 years, while emerging economies have experienced significant growth in electricity consumption, increasing to an average of nearly 4,000 kilowatt-hours (kWh) per capita annually, energy-poor nations have seen only modest gains to an average of about 500 kWh per capita. Figure 3 illustrates this further, depicting the electricity consumption per capita across various African countries compared to the global average. It shows that not only is SSA's electricity consumption per capita extremely low compared to the world average, but it also demonstrates stagnant growth over the years. This limited growth in electricity consumption reflects the broader economic limitations in SSA, where insufficient energy availability continues to act as a bottleneck for economic expansion and development.

From a sectoral breakdown of SSA's energy consumption (Figure 4), the residential sector forms the largest share of energy demand, which is indicative of the region's reliance on basic energy needs. This stands in contrast to the breakdown of global energy consumption, where sectors like transport and industry dominate energy use, supporting advanced economic activities. The lack of a significant energy demand from more energy intensive sectors suggests limited industrialization and a slower pace of infrastructure development, reinforcing the urgent need for abundant energy use and equitable allocation to foster sustainable economic growth in the region.

With increasing energy use often serving as a marker of increased opportunity and improved well-being, it is evident that most African countries require new pathways of energy abundance to meet their development goals.

The relationship between energy consumption and economic growth is undeniable. This positive correlation was first established by Kraft and Kraft (1978) and has since been reinforced by numerous studies (Toman and Jemelkova, 2003; Mehrara, 2007). More recent research highlights the heightened relevance of this energy-growth nexus in the context of SSA, where the connection between energy access and economic development is especially pronounced (Menegaki and Tugcu, 2016; Zerbo, 2017).

This nexus between energy and development becomes particularly critical when viewed through the lens of the Multidimensional Poverty Index (MPI). Developed by the Oxford Poverty & Human Development Initiative (OPHI) in collaboration with the United Nations Development Programme (UNDP) in 2010, the MPI employs a range of indicators – namely, education, health, and standard of living – to provide a comprehensive measure of poverty (UNDP, 2021). A report by OPHI (2021) highlights that of the 922 million people globally classified as energy-poor, 75% are also multidimensionally poor, with 96% of these individuals lacking access to clean cooking fuel, 86% living in unsafe housing, 83% lacking adequate sanitation, and 55% relying on unsafe water sources. These highlight the even more important intersection of energy and development in sub-Saharan Africa, a region with pressing economic and social challenges. More importantly the MPI further emphasizes the need for a high energy future to elevate living standards and improve the overall quality of life.

Alleviating poverty, raising living standards, and fostering economic growth are all intricately linked to how energy is produced, distributed, and consumed. “Declaring success with light bulbs and a solar-powered sewing machine is selling billions of people short” (WEF, 2019). In a global market where affordable, reliable, sustainable and modern energy are key ingredients for a competitive economy, poverty eradication, and inequality reduction, Africa and even more so, African cities need energy for development, a lot more than there is at the moment, and they need it now (Sokona, Mulugetta and Gujba, 2012).

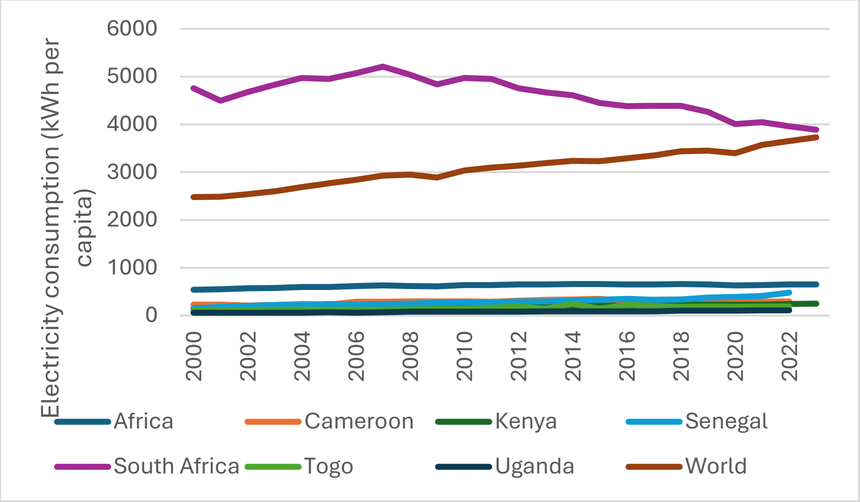


Figure 3. Trends in electricity consumption per capita globally and across selected African countries.
Data obtained from (Ember, 2024)

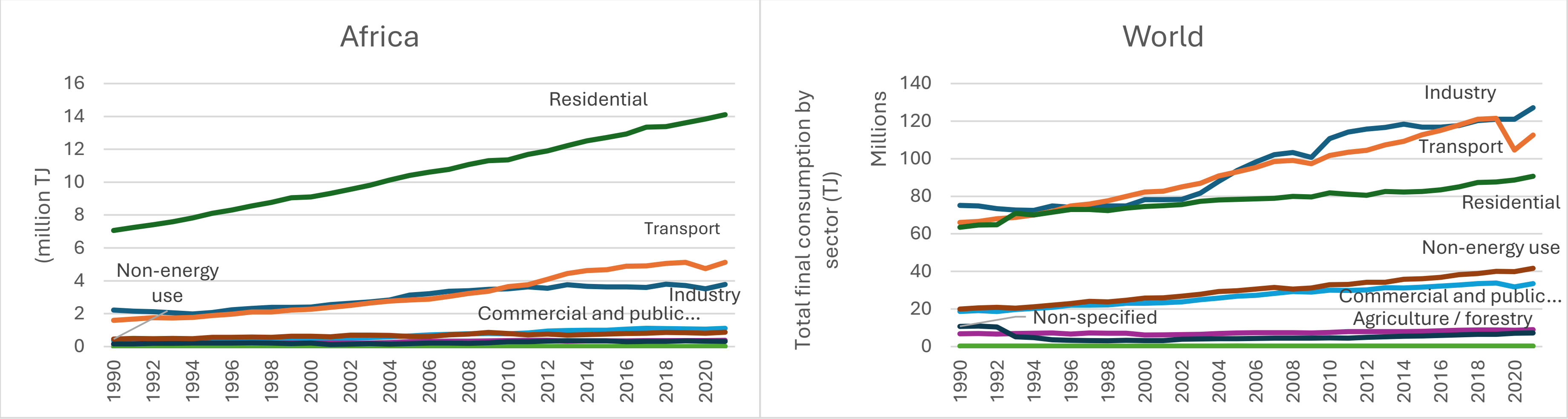


Figure 4. Trends in sectoral energy consumption patterns globally and across selected African countries.
Data obtained from (IEA, 2023b)

2.2. Inequalities in SSA

Inclusive growth, job creation, and poverty alleviation are the top priorities in Africa's Agenda 2063 (African Union Commission, 2015). At the same time, despite Africa contributing the least to the world's CO_2 emissions, African countries have committed to addressing the global climate crisis through the Paris Agreement.

These climate commitments have already spurred a continent-wide push towards low-carbon pathways, with many nations advancing renewable energy projects and prioritizing energy efficiency. Likewise, African leaders are increasingly integrating climate objectives into their development agendas, recognizing the link between resilient energy systems and broader socio-economic progress (Vanegas Cantarero, 2020; Mutezo and Mulopo, 2021). Yet, this clean energy transition is currently unfolding within a landscape marked by deep system inequalities, particularly pervasive in Africa, where governments – both national and local – are burdened by the weight of some of the most glaring income disparities globally (Kartha *et al.*, 2020) and are confronted with the largest unelectrified population (IEA, 2022b). At the same time, these decision makers must carefully strategize for the world's fastest-growing cities (United Nations, 2018b), while contending with deficient infrastructure and the distressing scarcity of access to climate finance, among several other issues. Further, inequality from the uneven impacts of climate change is now acknowledged as a decisive force linked to various issues, from environmental performance to domestic terrorism (Hubacek *et al.*, 2017; Krieger and Meierrieks, 2019).

Inequality considerations, particularly in heavy fossil fuel dependent regions, have sparked global debates regarding the speed of the energy transition, and more broadly, around the urgent need to rectify the deep injustices ingrained within current energy systems. These have brought the discourse on a "Just" or "Equitable" energy transition to the forefront, at the heart of which is the recognition of the importance of protecting marginalized groups and vulnerable individuals from bearing disproportionate impacts in this transformation process, and emphasizing the need to incorporate their needs and perspectives into the intricate fabric of planning and implementing clean energy initiatives (Ambole *et al.*, 2021; Streimikiene *et al.*, 2021).

Most studies have usually discussed and analysed inequalities in terms of income or some related monetary measure. However, disparities in energy access and use both within and across countries mirror or are at times starker than inequalities in income (Pachauri, 2014a).

Figure 5 shows an intriguing picture of energy use inequality between the richest 10 percent and the poorest 10 percent of the population across 73 countries based on 2001 data (Pachauri and Spreng, 2012). This diversity in energy use across countries and income groups is often linked to income inequality, as well as production and consumption patterns (Pachauri, 2014a). Although equally relevant, much of the current research on energy and inequality have a strong country-focus, especially addressing the wealth and energy poverty link in high income countries (Galvin, 2019, 2020b).

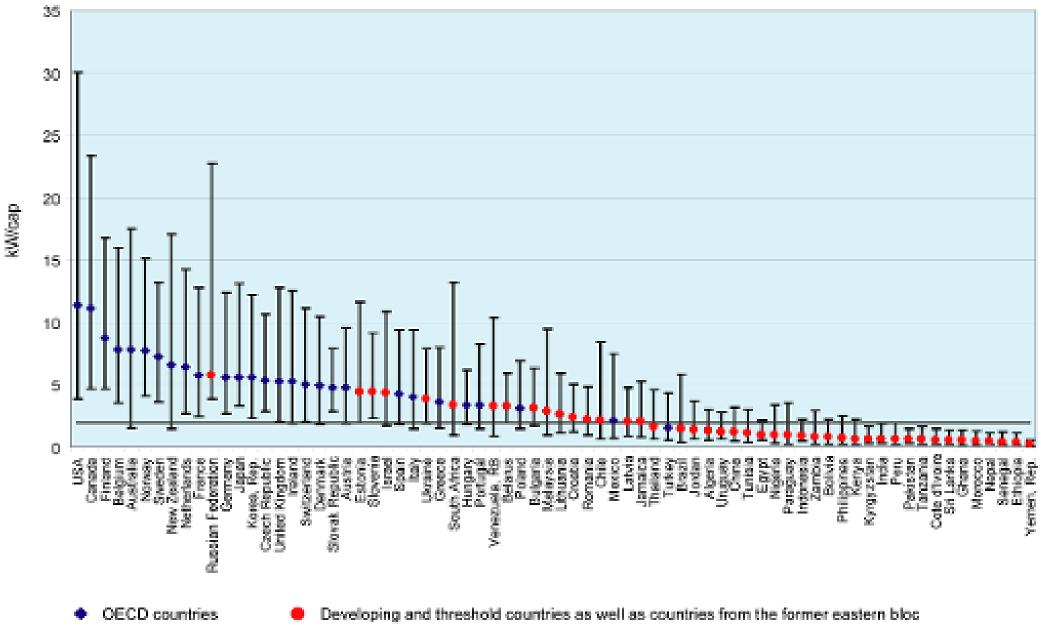


Figure 5. Energy consumption per capita inequalities between and within nations.
Image sourced from (Pachauri and Spreng, 2012)

Evidence suggests that energy inequalities are not only prevalent at the national level but can also be significant at the subnational level. A case in point is Kampala, the capital city of Uganda. To illustrate this, a stylized income-CO2e elasticity model is employed, adapted from the methodology proposed by Chancel and Piketty (2015) - see equation 1. This model allows to estimate the individual GHG emissions of various income groups based on the city's average emissions data.

$$CO_{2i} = f_i * \frac{CO_{2e_{tot}}}{\sum_{i=1}^{N} f_i * y_j^e} * y_i^e \qquad (1)$$

Where:

- fi is the total population share of income group
- i in total population,
- yi is mean income in group i,
- CO2etot represents total emissions in the country,
- N the number of income groups, and
- e is the income-CO2e elasticity.

We then divide CO2ei by the total population of group i to obtain per capita estimates.

Individuals in the top quintile (Q5) of Kampala's population often own multiple household appliances and use private transport, thereby consuming several times more energy and emitting twelve to twenty-five times more than individuals in the bottom quintiles. In fact, these embedded inequalities mean that those in the top quintile produce two-thirds of total city emissions, while the bottom quintile (Q1) account for just 2% (Figure 6). Yet Kampala's poorest residents live overwhelmingly in settlements most vulnerable to climate change. Worse, low-income households lack access to modern energy supplies, and still largely rely on traditional energy sources such as charcoal or firewood for cooking and heating, which can be degradative to health[2] (Yongoua Nana, 2021).

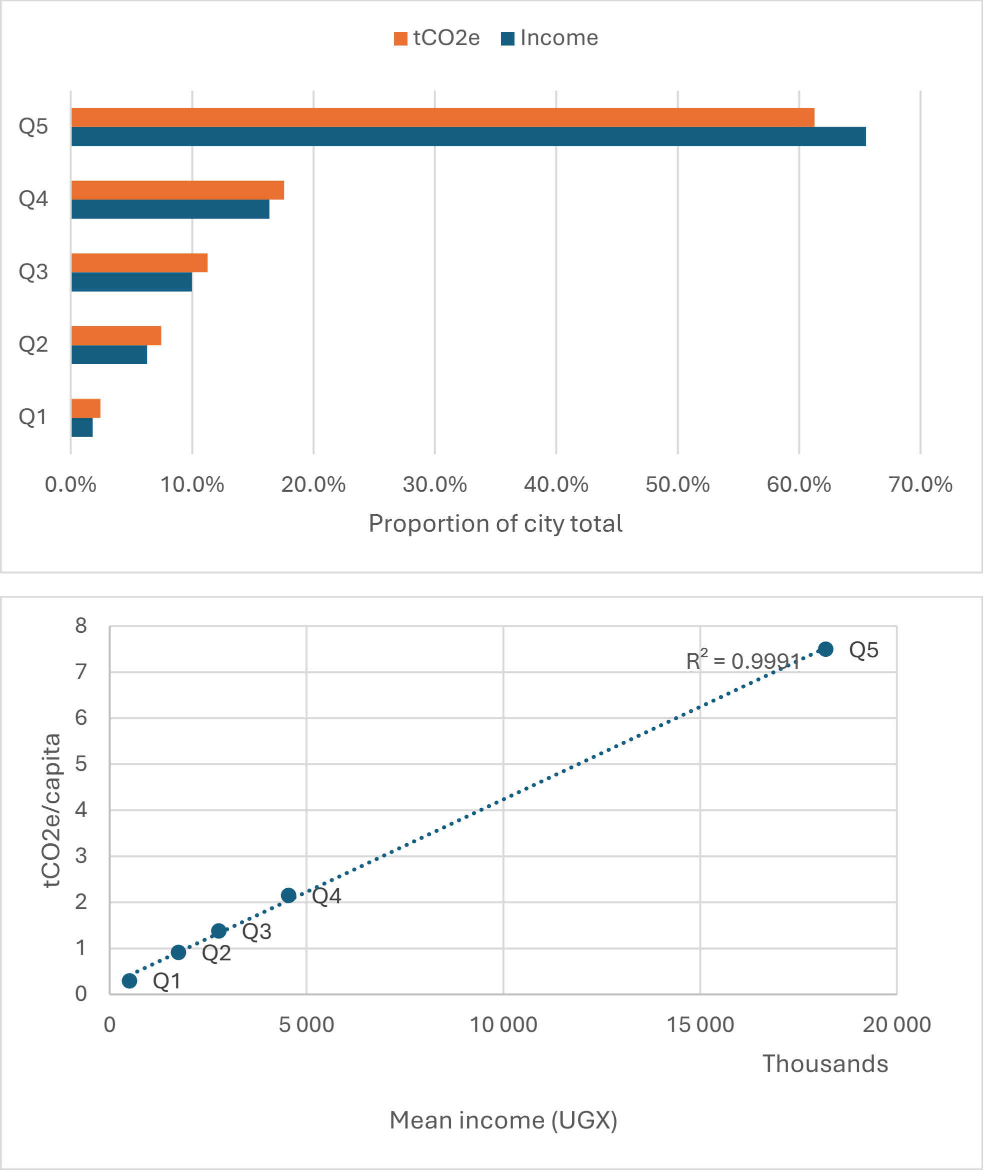


Figure 6. Income and GHG emissions distribution across quintiles in Kampala (2014). Author's own analysis

2.3. Response at local level

Over the past two decades, there has been a proliferation of city networks such as the C40 City Leadership Group, the Global Covenant of Mayors (GCoM), United Cities and Local Governments (UCLG), ICLEI and so many others (Acuto and Rayner, 2016; Bansard, Pattberg and Widerberg, 2017) that have been instrumental in supporting local climate action planning on a global scale. This movement is driven by the recognition that cities are major sources of global emissions,

---

[2] When these fuels are sourced through sustainable practices, the carbon emissions generated by individuals relying on these traditional fuels for domestic energy needs can reach near-neutral levels, as the CO2 released during combustion is effectively offset by regrowth cycles.

presenting a significant window of opportunity for emissions reduction. Cities are more agile compared to national governments, with less bureaucratic inertia, and are economic engines as well as centres of innovation – key factors in rapidly advancing climate agendas.

African cities have also increasingly joined the global dialogue on climate action, with over 30+ local climate action plans developed over the last decade through flagship initiatives such as the Covenant of Mayors in Sub-Saharan Africa (CoMSSA) and Climate Action Planning Africa Programme, led by C40 Cities, (C40, 2021; CoMSSA, 2024b). Figure 7 shows the spatial distribution of all existing climate plans to date. In some African cities, leaders have made local climate change planning a cornerstone of their sustainability efforts. This strategy offers the exciting possibility that the challenges of economic growth, energy access, and environmental protection can be balanced effectively.

Figure 7. African cities with a climate action plan as of October 2024.
Author's analysis based on (C40, 2022a; CoMSSA, 2024a). Both initiatives maintain online repositories of city climate action plans, accessible via the following CoMSSA repository and C40 knowledge hub repository.

Prior to 2013, such work had only been implemented in South Africa in a significant way (Winkler *et al.*, 2006; SEA, 2007). Only around the build-up to COP21 in 2015 did such urban-focus work extend to the rest of SSA in a more comprehensive manner. One important frontrunner was the "Supporting African Municipalities in Sustainable Energy Transitions" (SAMSET) programme that paved the way through the development of energy models and datasets for six SSA municipalities in the three partner countries of Uganda, South Africa and Ghana (SAMSET, 2014), with the objective of informing policy and strategy formulation and since then been replicated in several other SSA cities via the CoMSSA and C40 CAP Africa Programme, providing a baseline to support evidence-based planning.

This urban focused work has clarified the practical steps needed for a more sustainable energy future in cities. These measures include better planning to improve public transport and reduce congestion, stricter building regulations for enhanced efficiency, widespread electrification and industrial energy efficiency programs, optimized biomass use for cooking, and support for decentralized renewable energy solutions like distributed solar PV, among other strategies (Bawakyillenuo *et al.*, 2018).

It however emerges that in all those key areas, local governments need to be capacitated and have little rule-making authority. Scholars examining climate change governance in urban contexts highlight several systemic barriers that undermine the ability of cities to implement these crucial interventions. These barriers include constitutional ambiguities that constrain local governments' role in national climate policy, the lack of a comprehensive national climate framework, and insufficient financial support from central governments. Moreover, many cities struggle with a lack of cross-sectoral coordination within municipal administrations, leading to fragmented climate strategies (Tait and Euston-Brown, 2017; Hickmann and Stehle, 2019; Pasquini, 2020; REN21, 2021).

In South Africa, for example, these challenges are exacerbated by the state-owned utility, Eskom, which holds a monopoly on energy generation and relies predominantly on coal. This reliance not only hampers cities' efforts to integrate renewable energy but also limits their ability to reduce GHG emissions. Additionally, South African local governments’ heavy dependence on revenue from electricity sales presents a direct disincentive to promote energy efficiency measures, as lower energy consumption would reduce their primary source of income (Baker and Phillips, 2019).

Beyond the limited municipal mandates and climate governance challenges, a major constraint to local action has been the lack of granular city-level energy data to inform decision-making, which remains one of the biggest challenges to enable cities to develop proactive energy and climate governance frameworks (Avila *et al.*, 2017; Ouedraogo, 2017). Furthermore, despite a growing literature on SSA’s energy picture, they have often had a regional, or country focus rather than having a more specifically city perspective. The lack of urban energy data has been a motivating factor for current research by development agencies and other international partners to drive data creation, modelling and policy support work that has a specifically urban focus such as the work led by the CoMSSA or C40 cities. Yet, it’s still not enough. There may ‘never’ be enough time and resources for these customized technical and financial assistance to be rolled out to the several thousands of other SSA cities in dire need of data.

From an equity standpoint, several actors have equally viewed local CAPs as a critical mechanism for tackling the unequal exposure of marginalized communities to the adverse effects of climate change and energy poverty. For instance, low-income households often rely on inefficient biomass for cooking, which exposes them to harmful air pollution, resulting in severe health risks such as respiratory diseases. Furthermore, these communities are more likely to live in informal settlements that are poorly equipped to withstand climate-related disasters like floods and heatwaves, exacerbating their vulnerability to climate change (Olawumi Israel-Akinbo, Snowball and Fraser, 2018; Ballesteros-Arjona *et al.*, 2022). But to what extent are African cities incorporating equity into their climate and sustainability plans?

2.3.1. Evaluating equity within local climate action plans in African cities

Like their European and North American counterparts, many African cities have adopted climate action plans, albeit within distinct socio-political contexts characterized by a combination of rapid urbanization, clean energy access, and economic challenges. By applying the framework of absent and present equity considerations – as adapted from Waud's analysis of European cities' climate actions (Waud, 2018) – this section reviews ten climate action plans from African cities, examining the extent to which these plans incorporate considerations of equity or social justice.

The review involved searching for keywords[3] related to equity. These keywords were derived from the guiding principles in the C40 network and Covenant of Mayors in Sub-Saharan Africa frameworks (Palermo *et al.*, 2018). Beyond keyword searches and surface-level mentions, the review also examined how these keywords were embedded within broader urban sustainability goals, such as quality of life, and social cohesion.

Category	**Cities**
Absent	*None*
Isolated	Kasese, *Uganda* Accra, *Ghana* Tsévié, *Togo* Dakar, *Senegal*
Integrated	Yaoundé, *Cameroon* Nairobi, *Kenya* Cape Town, *South Africa* Lagos, *Nigeria* Freetown, *Sierra Leone* Addis Ababa, *Ethiopia*

Table 1. Cities with CAPs where equities are generally absent, isolated or integrated

Table 1 provides a summary of the assessment, categorizing the cities' CAPs based on whether equity considerations are absent, isolated, or integrated. A general observation is that, in contrast to European climate action plans (Waud, 2018), African climate action plans frequently foreground justice and equity as core components, despite being in their initial iterations, with the exception of Dakar and Cape Town. This emphasis arises for two key reasons.

First, local stakeholders in African cities have a heightened awareness of existing inequalities, with issues such as energy poverty, inadequate infrastructure, air pollution and the disproportionate exposure of disadvantaged communities to climate hazards easily observable realities in the African urban context. This awareness often informs and shapes stakeholder discussions. As a result, fairness and equity often become essential considerations, rather than as peripheral concerns.

Second, as global climate change efforts have intensified, there has been a broader recognition of the importance of equity considerations in climate action planning. This growing awareness

---

[3] List of equity keywords in the African urban context: equity, inequality, affordability, engagement, stakeholders, energy poverty, low-income, socioeconomic, justice, underserved, disparities, shared benefits, resilience, community , co-benefits, marginalised communities and vulnerable

has informed the methodological frameworks that guide climate action, with equity becoming a more prominent principle over time. African cities, whose CAPs were developed more than a decade after their European and American counterparts, have benefited from this evolution, integrating equity more directly into their planning frameworks.

The CAPs with the most comprehensively integrated equity components are typically from C40 cities: Cape Town, Lagos, Freetown, Addis Ababa, and Nairobi. This integration is largely facilitated by the C40 network's framework, which prioritizes equity as a central tenet of climate action. For instance, the Freetown CAP explicitly outlines the transition towards a clean, accessible, and equitable urban energy system as one of its key goals, whereas the Lagos CAP emphasizes the objective of equitably distributing the broader benefits of climate action.

2.3.2. Gaps in the integration of equity considerations in local climate plans

However, one significant limitation of these CAPs is that equity considerations are often described as co-benefits or aspirational goals, without enough detail on how specific actions will achieve these outcomes. Although the CAPs broadly embrace economic, social, ecological, technological, and even cultural aspects, many discussions prioritize creating smart, green, or economically competitive cities, with at times a weaker stance on equity. Even when social dimensions like livability, well-being, and quality of life are considered, equity issues remain underdeveloped, with benefits assumed to trickle down evenly, overlooking disparities in access, decision-making, and representation among different social groups (Avelino *et al.*, 2024a).

The weak connection between existing inequalities and the proposed actions is primarily due to a lack of comprehensive and disaggregated data on inequalities. The analyses informing these CAPs while greatly contributing to generating urban energy datasets, frequently lack nuanced insights into the differential impacts of climate actions on diverse social groups, particularly marginalized communities. The modelling exercises subsequently focus on more macrolevel outcomes such as energy access, emissions reductions or clean energy technologies deployment targets. Without a nuanced view on the departing point from an inequalities standpoint, it is challenging to develop policy interventions and measures that have clearly predictable equitable outcomes and shared climate action benefits.

There is a clear recognition that local climate action planning in Africa faces with the wicked problem of balancing sustainability goals - i.e. contributing fairly to global efforts against climate change – while simultaneously addressing local needs for economic growth and energy abundance. This challenge is further compounded by the need to tackle entrenched inequalities within urban energy systems. Achieving these several development objectives requires innovative pathways for development, but more importantly, it necessitates a much clearer understanding of existing energy inequities in urban areas and the differential impacts of proposed climate action pathways across various social classes. Anguelovski et al., (2020) and Baker et al., (2023) frame it as a critical need for detailed evidence-based analyses of urban inequalities, emphasizing not only the procedural and recognitional dimensions but also the need to consider relational and intersectional power structures for transformational changes.

2.4. Gaps in existing literature

There has been an increased scholarly attention to understand the development dilemma, mainly economic competitiveness and energy abundance within the guiding framework of justice, equity and sustainability.

This section reviews the existing body of work, pointing out gaps in terms of i) scope i.e. a lack of an urban focus; ii) the poor understanding to date of the state of energy and emissions in African cities and iii) the gap in inequality research on African cities

2.4.1. Gaps in urban sustainable development pathways literature

The literature on energy consumption and economic growth in Sub-Saharan Africa (SSA) predominantly focuses on regional or country-level analyses, often overlooking the urban dimension that is critical for formulating targeted local policies.

(Kahsai *et al.*, 2012) discuss the energy consumption and GDP nexus in SSA, focusing on income-level classifications and the interdependence between energy consumption and economic growth. One key finding of this study is the identification of the positive correlation between energy consumption and economic growth in middle-income SSA countries, suggesting that increasing energy availability could stimulate growth. However, their study does not differentiate between urban and rural settings, missing an opportunity to explore urban energy dynamics in greater detail. Similarly, the study by (Richard, 2012) applies an asymmetric cointegration approach to analyse the relationship between energy consumption and economic growth in twelve SSA countries. A significant contribution of this study is its analysis of how conservation policies can have asymmetric effects on energy consumption, providing valuable insights for policymakers interested in demand-side management.

(Kebede, Kagochi and Jolly, 2010) analyse energy demand in SSA across different regions, highlighting the heavy dependence on traditional biomass and limited use of commercial energy like electricity. The study presents the energy transition challenges faced by SSA, particularly in reducing reliance on biomass. While this study provides insight into the differences between regions, it lacks an urban-specific focus, leaving a significant gap in understanding how urbanization affects energy dynamics within specific cities and the corresponding implications for policymaking.

The study by (Dioha and Kumar, 2020a) presents a residential energy model for Nigeria, highlighting energy transitions in both urban and rural households. While this work makes strides in addressing the rural-urban energy divide, it tends to stylize modelling inputs and outcomes across all urban jurisdictions, thereby weakening the ability to account for local specificities. Such stylization overlooks the distinct energy challenges faced by different urban centres, ultimately limiting the relevance of findings for localized urban policymaking.

(Bazilian *et al.*, 2012) emphasize that most energy planning in SSA looks at aggregated country-level projections for installed generation capacity without giving attention to the needs and characteristics of individual urban areas. Importantly, the study sheds light on the inefficiencies of aggregated energy planning and its inability to cater to localized energy needs, which can hinder the effectiveness of electrification programs. This lack of granularity hinders the formulation of policies that cater to urban contexts, where energy access, reliability, and infrastructure constraints can differ significantly from rural areas. The review by (Musonye *et al.*, 2020) highlights the need for improved planning mechanisms that would support decentralized energy solutions for both urban and rural settings in SSA. A notable finding is the call for integrating grid extension with decentralized generation to achieve universal access. However, the focus on integrated energy systems and grid extensions tends to aggregate urban and rural challenges without an in-depth exploration of specific both rural and urban specificities.

2.4.2. Gaps in urban energy and emissions profiling literature

Most of the existing literature profiling energy in Africa has focused predominantly on the residential sector, emphasizing household energy use patterns, access, and transitions.

Prevailing social science approaches utilized in household energy consumption research tend to focus on regular, everyday determinants of household behaviour (Makonese, Ifegbesan and Rampedi, 2018; Winkler, 2018; Ye, Koch and Zhang, 2018). Mosner-Ansong et al., (2024) surveyed major cities of Ghana to ascertain the awareness and assertiveness of households as far as efficient usage of energy is concerned and found that behaviours toward energy-efficient technologies and ways to manage household consumption could be a major step towards improved energy usage, and minimizing pollution. (Tetteh and Amponsah, 2020) examined the influence of smart home adoption on efficient energy usage and argued that this leads to improved energy usage and the betterment of the lives of the households.

These studies' conceptual frameworks sidestep economic inequality, overlooking its influence on home ownership, power dynamics, and, ultimately, energy consumption. Even where such studies tend to shed light on the energy and carbon inequalities in Africa, they have primarily relied on input-output tables or social accounting matrices to attribute emissions to households, using aggregated household expenditure data (Baloch *et al.*, 2020a; Odhiambo, 2020; Adeleye *et al.*, 2021; Ogede and Tiamiyu, 2022). Yet, such aggregated monetary household expenditure data suffer from a lack of granularity and feedback validation from measurable metrics on fuel or end uses.

Only recently has urban energy and emissions profiling gained momentum in Africa, mainly through climate action planning efforts led by international city networks and local governments. However, there is yet to be a more consolidated analysis of emerging energy use and emissions trends across all key economic sectors within African cities, beyond just the residential sector, to include other key economic sectors, such as transportation, industry, and commercial activities.

These gaps limit our understanding of how different urban sectors contribute to overall energy demand and emissions, as well as how sectoral interdependencies affect urban energy systems, to better inform urban policy making.

2.4.3. Gaps in urban energy inequality literature

The existing literature on energy inequality and/or justice in Sub-Saharan Africa has often been approached from several angles, with a strong emphasis on the relationship between poverty, income inequality, and emissions.

(Appiah, Li and Korankye, 2021) examine the interaction between energy use, industrialization, and CO2 emissions, noting that urbanization and fossil fuel consumption have significant impacts on emissions. The study emphasises the importance of policies that promote energy conservation and reduce CO2 emissions to achieve sustainability in the region. Akrofi et al. (2024) review injustices within renewable energy projects in Africa through a systematic analysis of 26 studies from 11 countries. They identify distributive, procedural, recognition, and restorative injustices, with distributive issues, such as resource conflicts and disparities in project benefits, making up the majority (58%). They argue that these injustices lead to inequalities, resource dispossession, and other socio-economic effects, highlighting the need for a context-specific approach to ensure justice in Africa's energy transition. The work presented in (Ikejemba and Schuur, 2020) examined the societal benefit of renewable energy projects in 29 projects implemented in 10 SSA countries and it was demonstrated that public funded projects have almost no social benefits just after the project delivery. In (Said and Acheampong, 2023), the impact of financial inclusion on energy poverty was examined with 23 SSA countries used as case studies with data taken from the period of 2004 to 2019. Using techniques such as dynamic ordinary least square (OLS), canonical correlation regression, and completely modified OLS techniques, the results demonstrated a significant reduction in energy poverty due to financial inclusion though the impact differed significantly in various countries.

(Maji, 2019) investigates the impact of clean energy and inclusive development on CO2 emissions in Sub-Saharan Africa, showing that renewable energy can help reduce emissions. However, inclusive development efforts remain limited, particularly in terms of including marginalized groups in energy planning. This study highlights the need to incentivize renewable energy adoption while ensuring that disadvantaged communities are part of the solution to environmental sustainability. (Baloch *et al.*, 2020b) analyse the relationship between poverty, income inequality, and CO2 emissions, finding that both poverty and income inequality contribute to higher emissions in Sub-Saharan Africa. The study recommends targeted poverty reduction measures to mitigate emissions, emphasizing the role of inclusive development in achieving sustainability goals.

(Simplice A. Asongu and Odhiambo, 2021) explore the link between income inequality and renewable energy consumption, suggesting that higher inequality in SSA tends to reduce renewable energy uptake. They recommend policies aimed at maintaining income equality to enhance renewable energy adoption, which is crucial for reducing CO2 emissions. The study by (Simplice A Asongu and Odhiambo, 2021) further provides insights into avoidable thresholds for CO2 emissions and the need for complementary policies that promote renewable energy alongside efforts to reduce inequality. The research offers actionable policy thresholds that can be leveraged by policymakers to achieve both sustainable energy use and equitable development in the region.

While these studies contribute valuable insights into the dynamics of energy use, emissions, and inequality in SSA, they still fall short in terms of granularity, particularly at the urban level. The focus on broad national or regional trends means that the specific energy inequalities present in individual cities are often overlooked. Urban-specific analyses are essential to understand the spatial distribution of energy poverty, the role of local infrastructure, and the particular needs of different urban populations. Without such, policy interventions may lack the precision needed to effectively address energy inequalities and foster sustainable urban growth.

2.5. Literature on approaches to scenario design

Scenario design has emerged as a pivotal methodological approach for exploring possible futures and informing transformative change in energy systems, particularly in the face of increasing climate challenges and rapid technological changes. As defined by the Global Scenario Group, "a scenario is a story, told in words and numbers, describing the way events might unfold. If constructed with rigor and imagination, scenarios help us to explore where we might be headed, but more, offering guidance on how to act now to direct the flow of events toward a desirable future" (Raskin *et al.*, 2002).

In contrast to traditional forecasting, which relies heavily on extrapolating historical trends, scenario design involves constructing multiple plausible futures to illuminate complex interdependencies, evaluate trade-offs, and identify robust strategies (Dreborg, 1996; van Notten *et al.*, 2003). By accommodating uncertainties, scenarios serve not merely as predictive tools but as stimuli for innovation, stakeholder engagement, and informed decision-making. Their capacity to highlight distinct trajectories – ranging from conservative 'business-as-usual' projections to ambitious 'radical transformation' pathways – empowers policymakers and industry leaders to envision and actively shape desired futures. This is particularly valuable in contexts of high uncertainty and complexity, and data sparse environment, characteristics that define urban dynamics in Sub-Saharan Africa.

A key strength of scenario design in the energy domain lies in its ability to provide ways of thinking through transformative agendas. Scenarios, when co-created with diverse stakeholders, foster shared learning and challenge ingrained assumptions (Wangel, 2011). This collaborative approach enables participants to reflect on their priorities and to recognize system-level feedback that may be overlooked in more narrow or siloed analyses. Through participatory scenario building, the process exposes vulnerabilities in the existing energy infrastructure while pinpointing opportunities for policy intervention and technological breakthroughs (IPCC, 2018). In so doing, scenario exercises can inspire creative solutions and cultivate consensus around bold actions needed to meet ambitious climate targets.

Notably, the context in which scenarios are constructed is of paramount importance, as geographic scales and socio-economic conditions can significantly shape energy demand patterns and technological deployment (van Vuuren *et al.*, 2014). Although many global and national-level scenarios have been crucial in orienting policy frameworks, they often lack granularity for sub-national analysis. Consequently, local-specific challenges – including local resource availabilities, infrastructural constraints, and demographic realities – may remain unaddressed (Grubler, 2012). This shortfall highlights the need to develop place-based scenarios that accurately capture regional differences in both energy demand and supply potential (Hawkins and Sutton, 2009). By integrating local demographic data, economic structures, and cultural practices, such city-scale scenarios can yield more precise insights, thereby guiding targeted, equitable, and sustainable energy solutions.

When applied within energy modelling tools – such as the Low Emissions Analysis Platform (LEAP) and TIMES (The Integrated MARKAL-EFOM System) – scenarios act as foundational inputs and guide the simulation of energy flows, technology uptake, and policy outcomes (Heaps, 2008). Scenarios in this context result in modelled pathways. Here, scenario parameters typically encompass assumptions on socio-economic growth, technological cost curves, policy frameworks, and user behaviour. By systematically adjusting these parameters, researchers and decision-makers can experiment with "what-if" situations, thereby illuminating possible system trajectories under diverse conditions (Loulou *et al.*, 2016). This computationally driven scenario analysis not only identifies robust strategies but also highlights points of sensitivity helping stakeholders prioritize areas for further inquiry and policy development. Scenarios in the sense of modelled pathways provide results relating to energy, GHG emissions and energy inequality, and provide rigorous information to scenarios in Raskin et al's sense.

An increasingly urgent priority in scenario design is the integration of equity considerations, as energy transitions can exacerbate or alleviate socio-economic disparities. Technological innovations and policy incentives, if designed without due attention to social factors, risk perpetuating uneven access to energy services (Sovacool and Dworkin, 2014). Incorporating equity parameters – such as affordability, regional accessibility, and the distribution of costs and benefits – enhances the relevance and legitimacy of scenarios (Newell and Mulvaney, 2013). This may entail employing mixed-method approaches: for instance, using quantitative energy models in tandem with qualitative insights from stakeholder engagements or community dialogues (Böhringer and Rutherford, 2006). However, designing scenarios that meaningfully integrate equity considerations presents both methodological and practical challenges. Data limitations, particularly regarding distributional impacts, often constrain the ability to model equity implications comprehensively. Additionally, the multidimensional nature of energy justice - encompassing procedural, distributional, and recognition elements - makes it challenging to fully capture equity considerations within quantitative scenario frameworks (Carley and Konisky, 2020).

By developing scenarios that explicitly incorporate equity metrics, disaggregate impacts across income groups, and integrate the urban dimension, this research can contribute to understanding how different transition pathways might affect energy inequalities in African cities.

2.6. Theoretical approach

The thesis contribution is mostly analytical. Nonetheless, this section provides a conceptual framework from which to explore the transformations and pathways for change in an urban African context.

2.6.1. Working definitions of concepts

While the contribution of the thesis is not primary theoretical, clarity on concepts used is important. This part of the literature establishes working definitions for key theoretical concepts that underpin the research, providing the necessary analytical scaffolding for examining urban energy transitions through an equity lens. Rather than attempting to advance formal theoretical constructs, these definitions serve to clarify the conceptual boundaries within which the research operates and to ensure consistent interpretation of terms throughout the analysis.

i. Energy equity (also referred to as "energy justice")

Foundationally, the term energy equity stems from or is equivalent to the concept of energy justice (Baker, DeVar and Prakash, 2019). Energy justice or equity in the energy context builds on the well-established principles of environmental justice and the climate change movement. While environmental justice addresses the broad impacts on human health and the environment from pollution and infrastructure projects, energy equity specifically targets the effects related to the energy system.

Energy equity emerged to apply the principles of justice to energy production and systems, energy policies, energy activism, the energy trilemma, energy consumption, energy security, the political economy of energy, and climate change (Jenkins *et al.*, 2016a). While there is still inconsistencies in the definition and use of the term energy equity, it is commonly defined as "*a global (or local) energy system that fairly disseminates both the benefits and costs of energy services and one that has representative and impartial energy decision-making*" (Sovacool and

Dworkin, 2014; Jenkins *et al.*, 2016b; Jenkins, Sovacool and McCauley, 2018; Baker, DeVar and Prakash, 2019).

The aims of energy justice are (Monyei *et al.*, 2018; Baker, DeVar and Prakash, 2019):

- Achieve energy equity in the economic and social participation in the energy sector
- Ameliorate the economic, social, and health overload on the population that is disproportionately adversely affected by the energy system in place

Energy justice places a clear emphasis on the concerns of working-class people, Indigenous communities, and those historically marginalized by racial and socioeconomic injustice, as well as communities living on the front lines of pollution and climate change (referred to as "frontline communities"). The goal of energy justice is to provide all communities with inexpensive, sustainable, and democratically managed energy. Energy justice has three core principles as identified, which are procedural justice, distributive justice, and restorative justice (Wallsgrove *et al.*, 2021).

Although this thesis primarily focuses on quantifying inequalities – particularly distributive injustices – using selected equity metrics, the term 'equity' is used broadly throughout this document to encompass the multiple dimensions of energy justice.

ii. Energy democracy

Energy democracy is a concept that has emerged alongside the growing emphasis on renewable energy transitions, deeply rooted in the belief that energy systems must not only decarbonize but also democratize. This concept has both normative and pragmatic dimensions, focusing on enhancing public control and fostering more participative and equitable governance of energy resources (Szulecki, 2018). Originating as a social movement driven by activists seeking to resist the centralized, fossil-fuel-based energy regimes, energy democracy aims to decentralize energy governance and establish community-led and socially just energy systems (Burke and Stephens, 2017).

Energy democracy promotes the notion that energy should be controlled collectively, with active participation from citizens in decision-making processes regarding energy production, distribution, and consumption. The movement aligns closely with the ideas of participatory governance, civic ownership, and local autonomy in decentralized energy systems (Becker and Naumann, 2017). The key drivers behind this concept are a desire to disrupt existing power dynamics in the energy sector and create a system that is more accountable to local communities and diverse stakeholders (Wahlund and Palm, 2022).

There are three fundamental dimensions of energy democracy:

1. **Participatory Governance**: Energy democracy calls for a shift from centralized decision-making to more inclusive processes that actively engage citizens and communities. This aspect emphasizes the need for collective control and participation, allowing citizens to have a direct say in energy-related decisions, thereby increasing accountability and transparency in energy governance (van Veelen and van der Horst, 2018).

2. **Decentralization and Local Ownership**: One of the core ideas behind energy democracy is to encourage the decentralization of energy systems. By promoting local ownership—whether through community cooperatives, municipal projects, or individual

prosumers—energy democracy aims to empower communities, allowing them to benefit from and control their energy resources directly (Szulecki, 2018).

3. **Social Justice and Equity**: Energy democracy also emphasizes the importance of ensuring that energy systems are equitable. It focuses on dismantling the existing inequalities in access to energy and ensuring that marginalized and frontline communities have equal opportunities to participate in and benefit from renewable energy systems (Burke & Stephens, 2017). This includes advocating for affordable energy access and fair distribution of both costs and benefits (Wahlund and Palm, 2022).

In practice, energy democracy has been applied through various initiatives, such as community energy projects, cooperative ownership of renewable energy installations, and policies that support local decision-making in energy planning. These initiatives are seen as vital mechanisms to reduce dependency on large utility companies, democratize energy access, and support the transition towards a sustainable and resilient energy future.

The concepts of just energy transition and energy democracy are closely interrelated but distinct in their emphasis and scope. While just energy transition provides a framework for ensuring equitable distribution of costs and benefits in the shift toward low-carbon energy systems, energy democracy focuses specifically on transforming power relations and governance structures within these systems. Energy democracy can thus be understood as both a means and an end within the broader just energy transition agenda: as a means, it provides mechanisms for achieving procedural justice through democratic control and participation in energy decision-making; as an end, it represents the democratized energy system that a just transition aims to create.

In the context of African cities, the application of energy democracy holds significant potential, as local climate planning is already a form of energy democracy in practice through the devolution of the national government's previously centralized energy planning role. Given the challenges of energy inequality, lack of reliable access, and centralized energy monopolies prevalent across many urban areas in Africa, energy democracy could provide a framework for community empowerment and improved energy access. However, it is important that energy democracy in Africa is carefully adopted to ensure that focusing on communities as agents of change does not inadvertently create further inequalities.

iii. Just energy transitions

Just energy transition represents a specific application of broader just transition principles to the energy sector. While just transition originated in 1980s US labor movements as the "Superfund for Workers" - addressing worker displacement across multiple sectors including chemicals, mining, and energy (Stevis and Felli, 2015; Otlhogile and Shirley, 2023) - just energy transition focuses specifically on the socio-economic implications of transforming energy systems toward low-carbon alternatives.

The concept of just transition has gained significant international recognition, being incorporated into the Paris Agreement preamble and various national policies. The IPCC identifies core elements including investments in low-emission technologies, early assessment of social impacts, social dialogue, decent job creation, active labor policies, economic diversification, and gender-specific considerations (Lecocq and Winkler, 2023). Building on these foundations, just energy transition narrows the focus to energy system transformation, particularly emphasizing equitable distribution of both burdens and benefits as societies move away from fossil fuels s (Castán Broto and Westman, 2017; Avelino *et al.*, 2024b).

In contemporary use, just transition has become a guiding principle for achieving a fair shift towards sustainability by considering the socio-economic consequences of energy transitions and prioritizing the needs of marginalized populations, including frontline communities and workers whose livelihoods are closely tied to fossil-fuel-based sectors. This principle is grounded in justice and inclusivity, ensuring that vulnerable groups, often bearing the brunt of economic and environmental changes, are not left behind as economies shift towards carbon neutrality (C40, 2023).

The just energy transition framework focuses on three main components:

1. **Equitable Economic Opportunities**: Ensuring that the transition creates new economic opportunities, particularly for communities historically reliant on the fossil fuel industry. This includes reskilling and upskilling initiatives that enable workers to find employment in emerging green sectors (C40, 2023).
2. **Social Inclusion and Fair Participation**: Involving all stakeholders, particularly those most affected by climate change and energy transitions, in decision-making processes. This participatory approach, often termed procedural justice, ensures that policies are not only designed but also implemented in ways that reflect the priorities and needs of frontline and marginalized communities (Castán Broto and Westman, 2017).
3. **Environmental and Restorative Justice**: The just energy transition also encompasses restorative justice by recognizing and addressing historical environmental injustices. This aspect seeks to repair past harms and ensure that the benefits of new energy systems are distributed in a way that reduces inequality and fosters resilience (Otlhogile and Shirley, 2023).

In urban contexts, the application of just energy transition principles emphasizes addressing the particular challenges of cities, such as unequal access to clean energy and the need for sustainable urban planning. The idea is to integrate justice and sustainability by ensuring that urban energy policies do not inadvertently widen inequalities but rather contribute to reducing energy poverty, fostering community ownership of energy systems, and enhancing local resilience (Avelino *et al.*, 2024b).

The just transition framework also considers the political dimensions of sustainability transitions, acknowledging the challenges of path dependency within existing energy regimes. Transforming these systems requires broad-based cooperation between civil society, local governments, and private sector actors to push for systemic change that aligns with social justice and ecological goals.

iv. Energy inequality

Energy inequality refers to the uneven distribution of energy resources, services, and opportunities across different social, economic, and geographic groups. At its core, energy inequality manifests when certain populations have reliable and affordable access to energy (e.g., electricity, modern cooking fuel), while others must rely on lower-quality or more expensive sources – or simply go without. This disparity can stem from a confluence of historical, infrastructural, and policy-related factors (Sovacool, 2012; Jenkins *et al.*, 2016b). For instance, systemic underinvestment in disadvantaged areas often results in inadequate grid infrastructure or higher costs, rendering modern energy unattainable for many (Bouzarovski, 2018). Over time, such inequities become self-reinforcing, as communities lacking access to affordable and reliable energy struggle to develop economically, thereby perpetuating cycles of poverty and environmental stress. Furthermore, while energy transitions, such as shifts toward renewables, present opportunities for more sustainable outcomes, they can also exacerbate inequalities if they fail to consider the needs and constraints of marginalized groups (Jenkins *et al.*, 2016b; Baker, DeVar and Prakash, 2019).

Closely tied to the principles of equity and justice, energy inequality specifically focuses on quantifying and analysing disparities in energy use patterns and their underlying drivers. The concept of energy inequality speaks to the idea that not everyone starts from a level playing field. In a purely equal distribution model, resources might be allocated evenly across a population. However, because people and communities often have different needs, capabilities, and resources, an equal distribution does not necessarily guarantee an equitable outcome (Healy and Barry, 2017). Indeed, from an energy justice perspective, addressing energy inequality requires recognizing these inherent disparities and designing interventions that prioritize those who face the greatest hurdles in accessing and benefiting from energy services. The ultimate aim is to ensure that energy systems do not replicate or deepen existing socio-economic divides, but rather serve as a catalyst for inclusive growth and development.

The measurement of energy inequalities often employs tools from economic inequality analysis, such as the Gini coefficient and Lorenz curves, adapted to energy contexts. However, as Jacobson, Milman and Kammen (2005) note, energy inequality metrics must account for unique characteristics of energy consumption, such as the existence of basic needs thresholds and the role of energy efficiency in determining actual energy services received.

In the context of urban energy transitions, energy inequality takes on particular significance as cities often concentrate both wealth and poverty, leading to stark contrasts in energy access and use within small geographical areas. As demonstrated by Galvin (2020a) urban settings can amplify energy inequalities through spatial segregation, infrastructure access patterns, and the uneven distribution of energy-intensive amenities and services.

For this thesis, energy inequality serves as both an analytical lens and a measurable outcome variable. The research employs quantitative measures of energy inequality (particularly Gini coefficients) to assess the distributional impacts of different energy transition pathways. However, it also recognizes energy inequality as embedded within broader systems of social and economic inequality, requiring analysis that connects energy consumption patterns to underlying structural factors. This conceptualization of energy inequality complements rather than replaces the framework of energy justice. While energy justice provides normative principles for evaluating energy systems, energy inequality offers concrete metrics for measuring progress toward more equitable outcomes. Importantly, the thesis's focus on energy inequality helps bridge theoretical discussions of energy justice with practical policy analysis, providing quantifiable measures that can inform policy design while remaining grounded in broader equity considerations.

2.6.2. Quantifying inequalities

For the measurement of inequality, the Gini coefficient is the most used measure (James, 2016). The Gini coefficient’s most common application is in the measurement of income inequality. Developed by the Italian statistician Corrado, named after him, and published in 1912, the Gini coefficient permits inequality to be measured on a scale from 0 to 1 (Joe, 2023). The lower the value, the lower the existence of inequality, and the higher the value, the higher the inequality. When it is 0, it means that there is no inequality, and when it is 1, it means that there is perfect inequality with someone receiving all the income, and the others nothing. Sometimes, the Gini coefficient is expressed as a percentage from 0 to 100% and this is referred to as the Gini Index.

The Gini coefficient works hand-in-glove with the Lorenz curve as the Gini coefficient is linked to the Lorenz curve (Gastwirth, 1972). The Lorenz curve graphically represents the proportionality of a distribution as shown in the figure below (Zheng *et al.*, 2008). To put up a Lorenz curve, all the distribution's elements from the least to the most important must be considered. From the figure below, it is possible to define the Gini coefficient as two geographical areas.

The first area is the area between the perfect line and the Lorenz curve; that is area A.

The second area is the area under the perfect line; that is area A + B.

Since area A + B stands for half of the unit box $\left(A + B = {}^{1}/_{2}\right)$, it is possible to express the Gini Coefficient, G, as

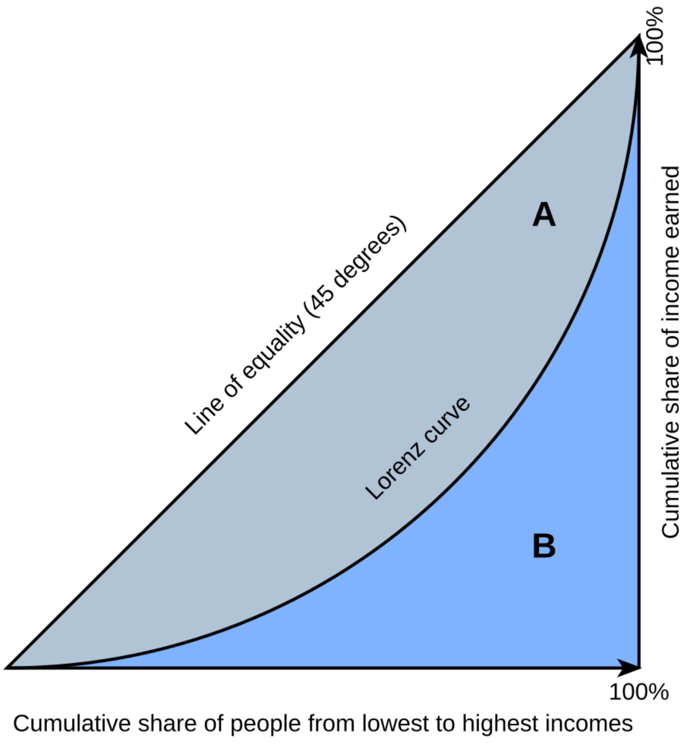
$$G = \frac{A}{A+B} = 2A = 1 - 2B \qquad (1)$$

From search, X_i's and Y_i's could be calculated and the area beneath the Lorenz curve obtained using equation (2) below.

$$B = \frac{1}{2}\sum_{i=0}^{n-1}(X_{i+1} - X_i)(Y_{i+1} - Y_i) \qquad (2)$$

Inserting equation (2) in equation (1) will yield the Gini coefficient.

$$GC = 1 - \sum_{i=0}^{n-1}(X_{i+1} - X_i)(Y_{i+1} - Y_i) \qquad (3)$$



Advantages of the Gini coefficient as a tool to measure inequality

- Its simplicity and ease of interpretation make it possible to be compared across countries.
- With the Gini coefficient, the change in income levels over a timespan can be analysed, and therefore increase or decrease in inequality can easily be spotted.
- It is possible to compare the income distribution across several population groups and several nations.
- Four crucial principles are satisfied with the Gini coefficient. These are;
  - ➢ Anonymity: Who the highest earner or the lowest earner is, is not important.
  - ➢ Independent of scale: The size and wealth of the economy are not taken into account.
  - ➢ Independent of population: How large or how small the population is, is not important.
  - ➢ Transfer principle: The resulting distribution tends toward equality if a rich person’s income is transferred to a poor person provided the transferred income is less than the difference.

Disadvantages of the Gini coefficient as a tool to measure inequality

- It is unable to distinguish various types of inequalities.
- In the case of a large and economically diverse country, the Gini coefficient will mostly lead to a higher coefficient compared to that of each of the regions of the country.
- If the Gini coefficient is applied to individuals instead of households, the results will be different.

- It is possible to have a country with the same Gini coefficient but yet their income distributions are different. This is because, even with different Lorenz curve shapes, the resulting Gini coefficient could still be the same.
- In a situation where high-income households can efficiently use income more than low-income households, the exact amount of inequality might be understated by the Lorenz curve.

2.7. Thesis contribution

In light of the above discussion, this thesis addresses several critical gaps in the existing literature on urban energy dynamics in Sub-Saharan Africa, making three distinct contributions to knowledge.

First, the thesis presents the first comprehensive, multi-city analysis of urban energy consumption and emissions across key economic sectors in African cities. While previous studies (reviewed in Section 2.4) have typically focused on national or regional scales, this research provides a new granular analysis of energy use and emissions across the residential, commercial, industrial, and transportation sectors across six diverse urban contexts. Through unique access to detailed municipal data from cities ranging from metropolitan centres like Cape Town to smaller towns like Tsévié, the research establishes new benchmarks in African urban energy analysis and reveals previously undocumented patterns in sectoral energy use and emissions.

Second, the thesis makes methodological contributions through its development and implementation of the Urban Household Energy Model (UHEM) framework and its application of city-level datasets. The UHEM represents a custom-built analytical approach - a transparent and replicable bottom-up modelling framework, built on the LEAP platform, to analyse household energy inequalities in African urban contexts. This bottom-up framework integrates city-specific socio-economic data with detailed end-use energy demand modelling. For each city, households are stratified into quintiles by income and electrification status, enabling nuanced analysis of energy consumption and GHG emissions at the household level. The successful collection, validation, and analysis of these datasets demonstrates the feasibility of detailed urban energy modelling in data-sparse environments, while also highlighting specific areas where data collection efforts should be prioritized. The thesis augments these datasets through various modelling techniques, such as the calibration of city-level energy balances and the use of logit and Weibull functions to address data gaps, while maintaining data fidelity.

Third, the research advances both scholarly understanding and practical policy development through its mixed-methods assessment of energy transition policies. By evaluating existing policy interventions and modelling alternative scenarios, the thesis provides novel insights into the effectiveness of different approaches to addressing energy inequalities. The research is unique in its detailed examination of how various policy measures affect different income groups, offering evidence-based guidance for designing more equitable urban energy policies. This contribution is particularly valuable given the growing emphasis on justice considerations in in the global energy transition.

By synthesizing the interconnected bodies of literature on energy, equity, and inequality, this chapter has laid the conceptual groundwork for the thesis. In Chapter 3, these theoretical insights will be translated into a robust methodological approach, demonstrating how the concepts outlined here can be systematically applied and evaluated in analytical contexts.

Chapter 3 : Methodology

Building on the theoretical and conceptual groundwork laid in Chapter 2, this chapter presents the methodological framework developed to examine household energy use and emissions inequalities across six Sub-Saharan African cities. The chapter begins by introducing the study areas and the rationale for their selection, highlighting how these cities represent different urban typologies across the region. It then details the development of the Urban Household Energy Model (UHEM), a bottom-up modelling framework built on the Long-range Energy Alternatives Planning (LEAP) platform, specifically designed to analyse energy consumption patterns across household income quintiles. The chapter further describes the data collection and processing approaches, including methods for addressing data gaps through synthetic data modelling. Special attention is given to the calibration process of the UHEM model and the calculation of inequality metrics, particularly the adaptation of the Gini coefficient for energy use analysis. The methodology outlined here provides a transparent and replicable approach for analysing urban energy inequalities in data-sparse environments while maintaining analytical rigor.

3.1. Study Areas

It is clear that to make findings on alternative development pathways that are more general than in the specific cities, it is important to include cities that illustrate various dimensions of SSA urban cities. This allows to understand how various urban settings relate to energy use, while also reducing the effect of important biases.

The selection of case study cities for this research evolved through a systematic process, beginning with an initial pool of fifteen municipalities across SSA where data had been collected through various technical assistance initiatives (CoMSSA, SAMSET, and C40 CAP Africa program). These cities – Accra, Addis Ababa, Awutu Senya, Bangui, Bouaké, Cape Town, Dakar, Garoua, Kampala, Kasese, Lagos, Nairobi, Polokwane, Tsévié, and Yaoundé IV – offered promising diversity in terms of population size, economic structure, and geographic distribution.

The final selection of the case studies was determined through a two-step process. In the first step, the methodology was piloted with one city, in this case Dakar, over a period of six months, to test the analytical framework and determine the depth of analysis required for meaningful insights. This piloting phase helped refined the methodological approach while also revealing the extensive data collection, processing and analysis needed for each city, informing the decision to focus on a smaller, strategically selected sample. Further, it was determined that a narrower selection would allow for a more detailed, context-specific inquiry.

In the second step following the pilot, it was therefore established that up to six cities would be studied which could be managed thoroughly within the constraints of time, resources, and the overarching research objectives.

The selection framework considered:

1. **Geographic distribution:** Sub-Saharan Africa comprises a vast and heterogeneous region. Careful consideration was therefore taken to ensure that all four sub-regions of SSA (East, West, Central and Southern Africa) were represented: West Africa (Dakar and Tsévié); East Africa (Nairobi and Kasese); Central Africa (Yaoundé IV); and Southern Africa (Cape Town) – see Figure 8. Further, the sample includes both coastal and inland cities across different climate zones, and therefore varying energy needs.

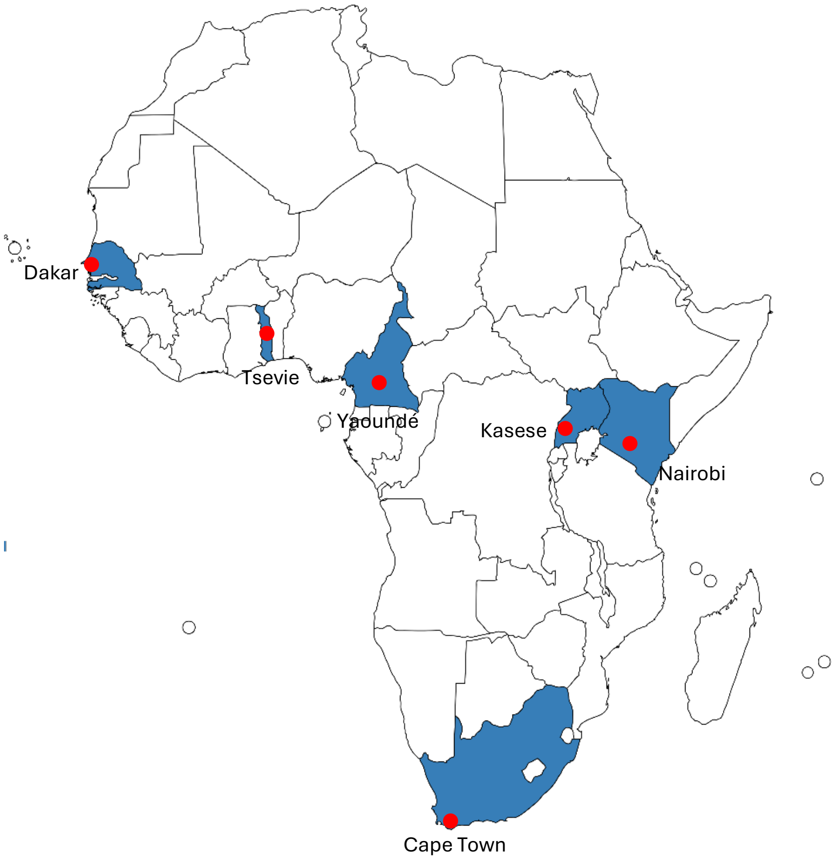


Figure 8. Geographical distribution of selected study cities

2. **Demographic and socioeconomic profiles:** The study cities allow a coverage of three distinct urban scales (metropolitan cities or urban cores, cities and towns) with population sizes across the six case studies dramatically varying from ~ 100 thousand people in Tsévié and Kasese to ~ 4 million in Cape Town and Nairobi. Similarly, the population density varies between 500 – 15000 people per km^2 which closely mirrors SSA's range (Combes *et al.*, 2023). This diversity helps interrogate whether development challenges and responses differ according to city size and economic status.
    a. Dakar, Nairobi and Cape Town are all metropolitan cities, with population sizes greater than 1 million people and often termed prime cities due to their very large sizes relative to other cities in the same country. These are largely industry or service-driven economies with clusters of financial institutions, food processing, or large industries, and relatively advanced physical infrastructure (Olomi, Charles and Juma, 2018).
    b. Yaoundé IV falls in the cluster of cities sometimes also called 'secondary' cities for their supplementary role to the primary cities (Ronnie, Lochner and Etienne, 2019). Yaoundé is a mostly service-based economy, dominated by trade financial services and a marked presence of the informal commercial sector.
    c. Lastly, Kasese and Tsévié are the least urbanized among the case studies and generally fall in the category of smaller towns. These two towns are mostly rural, and largely residential with agriculture generally the most common economic activity.

3. **Economic indicators:** Another selection criterion involved capturing a wide spread of economic indicators, exemplified by variations in GDP per capita and electrification rates across the six cities – see Table 2. GDP per capita ranges from ~$500 in Tsevié to ~$6000 in Cape Town, a more than twelve-fold difference that mirrors the wide economic disparities found across the region. Cape Town, for instance, represents a higher-income urban context with relatively high rates of electrification, reflecting stronger municipal infrastructure and revenue bases. In contrast, places like Tsévié and Kasese feature lower GDP per capita levels and less robust energy access – a condition that highlight the more resource-constrained realities of many secondary or emerging urban centres. By including such disparate contexts, the study mirrors the broad range of developmental trajectories found across sub-Saharan Africa.

4. **Data Availability and Quality:** Despite having the option to work with data from fifteen cities, prioritizing those with better-curated or more comprehensive datasets was crucial for ensuring analytical rigor. All six selected cities had comprehensive energy and emissions inventories, validated datasets through prior technical assistance programs, and very importantly, municipal cooperation agreements enabling data sharing.

After applying the above selection framework, a final group of six case studies was identified, comprising of **Dakar** (Senegal); **Yaoundé** IV (Cameroon); **Tsévié** (Togo); **Kasese** (Uganda); **Nairobi** (Kenya) and **Cape Town** (South Africa), were chosen based on the dimensions described above. While the final sample of six cities cannot claim to be statistically representative of all SSA urban areas, they allow both analytical depth and meaningful coverage of key variations in urban characteristics, therefore establishing a solid foundation for meaningful, policy-relevant research across the continent's diverse urban landscapes.

Cities / Towns	**Sub region**	**Population size**	**Population density (per km^2)**	**GDP Per capita (USD)**	**Electrification rate (%)**	**Main characteristics**
Dakar	West Africa	1 252 786	15 278	5 579	94%	**Metropolitan** - Home to Senegal's largest industrial facilities, commercial and financial institutions
Cape Town	Southern Africa	4 174 510	1 700	6 438	98%	**Metropolitan** - Cluster of financial institutions. Food processing industry and tourism
Nairobi	East Africa	3 973 981	6 748	3 474	97%	**Metropolitan** – largest industrial centre of Kenya and a cluster of financial institutions
Yaoundé IV	Central Africa	792 742	13 445	1 632	95%	**Secondary** - Yaoundé IV is one of 7 municipalities of Yaoundé, the capital city of Cameroon. Yaoundé IV is a service-based economy, with a large

						contribution from the informal sector
Kasese	East Africa	101 065	815	470	48%	**Town** - Major administrative town of Kasese district and largely agricultural-based economy
Tsévié	West Africa	103 049	596	519	24%	**Town** - Small town in the Maritime region, with an economy built largely on agricultural activities centred on crop production and livestock farming

Table 2. Typologies of studied cities.

Notes: Population and GDP figures are from respective base years: Cape Town (2018), Dakar (2016), Nairobi (2016), Yaoundé IV (2018), Tsévié (2017), Kasese (2016).
Information sourced from (McCall, Stone and Tait, 2017a; SEA, 2019c, 2019a, 2020b; World Bank, 2019a, 2019b; Yongoua Nana, Sambou and Nicholson, 2019a; NCC, 2022)

3.2. Research Ethics

This research was conducted under the ethical guidelines and requirements of the University of Cape Town's Faculty of Engineering and the Built Environment. Prior to data collection and analysis, ethics clearance was obtained from the Faculty's Ethics in Research Committee (approved March 2022).

The research primarily analyses existing municipal datasets that were collected through various technical assistance initiatives - namely the Covenant of Mayors in Sub-Saharan Africa (CoM SSA), Supporting African Municipalities in Sustainable Energy Transitions (SAMSET), and C40 Cities Climate Action Planning Africa Programme. Access to and use of these datasets was governed by formal data sharing agreements between the cities and these initiatives. For CoM SSA cities, this included explicit provisions allowing their non-confidential data to be used for research and publications by technical partners. Similarly, the SAMSET datasets were made publicly available through the project's online repository.

Nevertheless, to ensure transparency and maintain ethical research practices, formal communication was sent to all cities included in this study, informing them of the intended use of their data for this doctoral research. The study posed minimal risk to the participating cities, with the main consideration being the careful handling of potentially sensitive municipal data.

This ethical framework complements the author's positionality as both researcher and former technical advisor (detailed in section 1.4), helping to maintain appropriate boundaries between these roles while leveraging insights from both perspectives.

3.3. The LEAP modelling framework

Recent years have seen significant advancements in energy model development, with numerous new models and modelling features being introduced in the scholarly literature. Although several studies have attempted to review and identify the most appropriate analytical tools for energy system modelling in developing countries, their recommendations do not converge (Pandey, 2002; Hiremath, Shikha and Ravindranath, 2007; Bhattacharyya and Timilsina, 2010; Dioha MO, 2017). Further, these have usually considered model development at regional or country levels, often lacking the urban dimension. Despite the immense attention on the urban dimension of energy use and climate action planning in recent years, there remains a scarcity of discussion regarding suitable modelling tools and methods for integrated city-scale planning (Abbasabadi and Ashayeri, 2019; Sola *et al.*, 2020).

The work undertaken by Tait, McCcall and Stone (2014) as part of the SAMSET project attempted to fill-in the research gap by investigating suitable modelling tools for SSA cities. The research argued that bottom-up[4] models will be more suitable for developing urban energy systems using data inputs collected from consumers about equipment and appliances used for different sectors. It concludes that the Low Emissions Analysis Platform (LEAP) tool would be most useful in the African context where data availability is often a major challenge. Other modelling tools often used for city-scale analysis include MARKAL/TIMES, OSeMOSYS, and EnergyPLAN, all of which have proven valuable in contexts where cost optimization is a prerequisite and where high-quality, granular data is readily available. However, these tools often require extensive, detailed input parameters and are typically geared toward large-scale, national-level applications, making them less adaptable to the data-constrained environments of many SSA cities. By contrast, LEAP's flexible structure and comparatively lower data requirements make it especially suitable for supporting energy planning in contexts with limited information. Further, LEAP has been extensively used to support energy modelling efforts in over 200 countries, including city-scale analysis (Hu, Ma and Ji, 2019; SEA, 2019b, 2019a; Liu et al., 2021).

This study uses LEAP to construct bottom-up residential energy system models for each of the six selected cities. LEAP is a simulation accounting tool developed by the Stockholm Environment Institute (SEI, 2024). LEAP is a multifaceted analytical platform capable of accommodating varied energy planning approaches. For demand-side analysis, the system incorporates both granular, sector-specific consumption assessments (*disaggregated end-use analysis*) and broader economic trend integrations (*aggregate economic modelling frameworks*). Supply-side functionalities include systematic resource tracking, predictive scenario modelling, and optimization algorithms to identify cost-effective infrastructure pathways. This versatile modelling tool has been widely employed in developing countries for energy system analysis and climate mitigation studies (Dioha and Emodi, 2019; SEI, 2024). It offers an integrated approach, covering energy extraction, conversion, and consumption across all sectors of the economy. Additionally, LEAP facilitates cost-benefit analysis for various scenarios.

The model requires detailed data input in a hierarchical format across several modules, including socio-economic indices, demand, statistical differences, transformation, stock change, resources, and non-energy sectors. Economic variables such as gross domestic product, population, number of households, and industrial value addition are entered into the key assumption module. Projecting total final energy demand by sector involves parameters such as activity levels, energy production volume, and primary energy supply rate, while considering

---

[4] The bottom-up approach focuses on discrete energy-consuming devices that fulfil service requirements, including residential appliances and manufacturing systems. The top-down model on the other hand leverages organizational operational metrics – such as production outputs or service volumes tracked by institutions – and correlated aggregated operational data with facility-level energy demand patterns..

losses in the conversion sector. LEAP also incorporates environmental emissions from energy production and utilization through its technology emission database, which includes IPCC Tier 1 GHG emission factors.

Regarding the demand module, LEAP calculates final energy demand by multiplying end-use activity levels with their respective energy intensity. The model offers flexibility in estimating energy demand, including the final energy demand and useful energy demand approaches. The choice of method depends on the modeler, research question, and available data. Equations 4–5 describe energy demand and emissions calculations in LEAP (Heaps, 2020).

$$Final\ Energy\ Analysis, E = \sum_{i=1}^{n} Q_I \times I_i \tag{4}$$

where E= energy demand; Q_I= activity level and I_I= energy intensity

$$Useful\ Energy\ Analysis, E = Q \times \left(\frac{u}{n}\right) \tag{5}$$

where u = useful energy intensity and n= efficiency

GHG emissions are computed in LEAP as per equation 6.

$$G = \sum E \times Ef \tag{6}$$

where G represents the total GHG emission, E energy demand by a given fuel and Ef the emission factor of the fuel.

This LEAP-based approach thus provides the necessary platform and methodological grounding upon which the UHEM model – detailed in the following section – builds and extends its capabilities for more detailed urban energy analysis.

3.4. The Urban Household Energy Model

In this study, an Urban Household Energy Model (UHEM) was built, comprising energy models for each of the study cities, to investigate patterns in energy use and emissions across income quintiles of these urban settings. UHEM is a techno-economic bottom-up modelling analysis, based on the LEAP framework, covering all key household end-use sectors and fuel types – see Figure 9 and Figure 10 below.

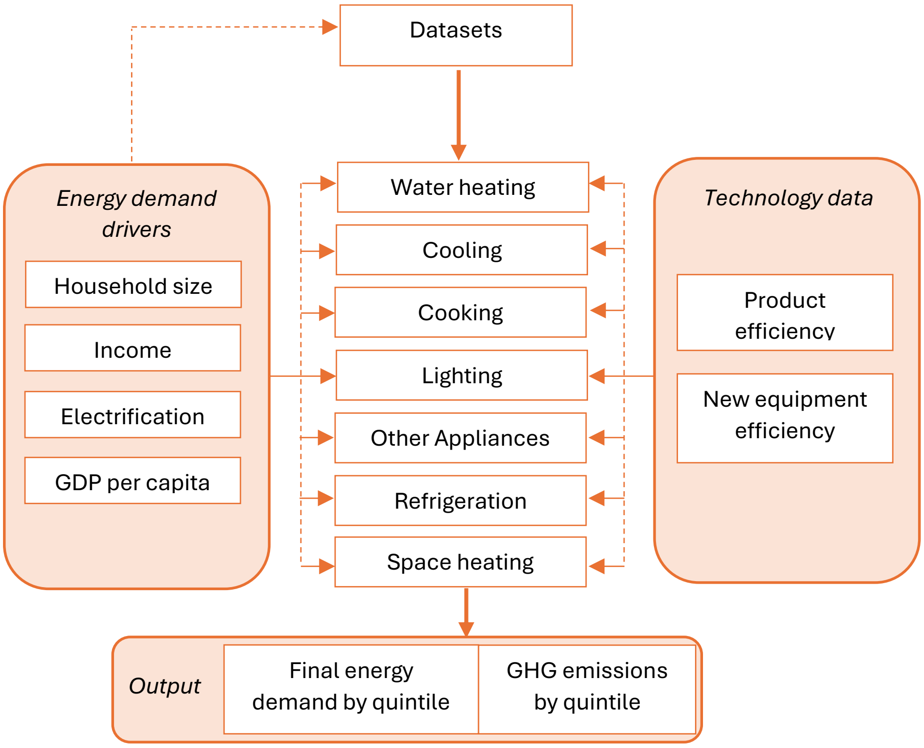


Figure 9. Energy demand model flow for each of the five selected cities in the UHEM model.

Figure 10 shows the structure of the household demand within the UHEM model. For each city, households are categorized into five income quintiles, Q1 through Q5, with Q1 representing the lowest income bracket and Q5 the highest.

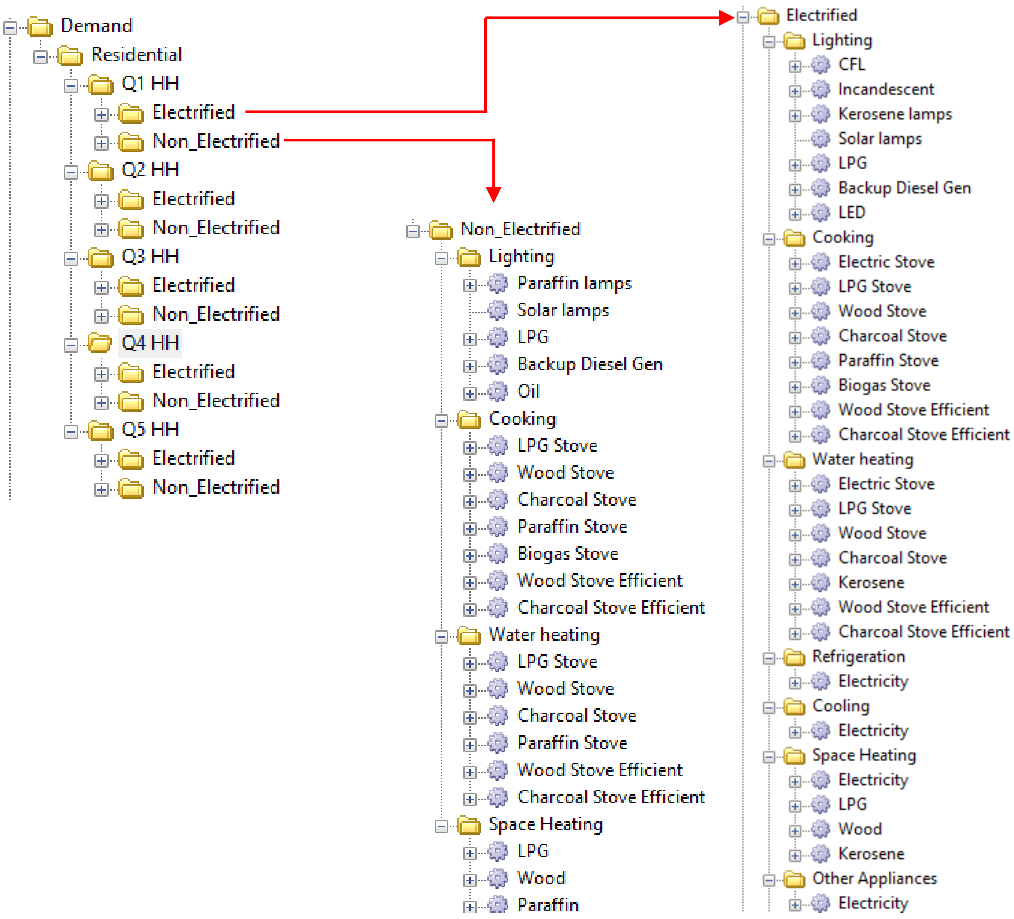


Figure 10. Tree structure applied to each city in the UHEM model.

Within each quintile, households are further grouped into two categories: electrified and non-electrified. For electrified households, the UHEM model considers seven end-uses, namely: cooking, lighting, refrigeration, cooling, water heating, space heating, and other appliances such as TV sets, CD players, and radios. In contrast, for non-electrified households, the model excludes all electricity-dependent end-uses, including refrigeration, cooling, and appliances. Further, each end-use in the model is associated with specific fuels typically used for that purpose, such as electricity for refrigeration or charcoal and wood for cooking - see Table 3.

Cooking	**Water heating**	**Lighting**	**Refrigeration**	**Space heating**	**Cooling**	**Other appliances**
Electricity	Electricity	Electricity	Electricity	Electricity	Electricity	Electricity
LPG	LPG	Paraffin (used in kerosene lamps)		LPG		
Charcoal (both regular and efficient stoves)	Charcoal (both regular and efficient stoves)	Solar (used in solar kits)		Paraffin		
Wood (both regular and efficient stoves)	Wood (both regular and efficient stoves)	Diesel (used in regular or back-up generators)		Wood		

Paraffin (used in paraffin stoves)	Paraffin (used in paraffin stoves)	LPG				
Biogas		Oil (other types of lamps)				

Table 3. Modelled end-uses and their associated energy fuels.

Exogenous inputs (based on available data or assumptions) in the model include GDP per capita, demographics, electrification, and income distributions. In cases where activity data were not available, they were estimated using bottom-up approaches, as detailed in section 3.6, and calibrated to align with the overall final energy demand from existing city datasets. Key outputs of the model, which are crucial for this study, include the final energy consumption and GHG emissions by income quintile, disaggregated by end-use and fuel type. Using these model outputs, further econometric analysis was conducted to compute the inequality coefficients of energy and GHG emissions within each city, measured using the Gini coefficient.

3.5. Calibration of the UHEM model

The calibration of bottom-up household consumption estimates in the UHEM model to the aggregate final household demand estimates in the base year for each city is not a straightforward open-loop extrapolation exercise. Instead, it involves an iterative process of aligning the cumulative bottom-up estimates with a city-level total consumption target. A limitation of this calibration is the unknown contribution of each income group to the city's total consumption, which could not be factored into the calibration. Equation 7 outlines the calculations used for the calibration process.

$$\min\left[e_n - \sum_j^5 \sum_i^k n_j \text{ x } p_{i,j} \text{ x } \bar{a}_{i,j}\right] \tag{7}$$

where:

- e_n is the actual city level consumption for a particular fuel type
- i is technology type
- j is the household income quintile
- p levels of ownership
- n number of electrified households per income category
- $\bar{a}$ aggregated annual consumption per fuel type

After computing bottom-up consumption estimates for each income group, the total is compared to city-wide consumption data, prompting adjustments to those variables that are most susceptible to significant uncertainty such as appliance-use patterns or technology efficiencies. This iterative process continues until the modelled total converges with the actual data. Although the exact consumption share of each income group remains unknown, the calibration relies on all available household and socio-economic information from the existing datasets or secondary literature to minimize error. The detailed data on household demographics, technology ownership, and usage intensities presented in Section 3.6 underpins these adjustments.

3.6. Data

This research builds on the studied cities' datasets collected through the SAMSET, CoMSSA and C40 CAP Africa Programme initiatives. The datasets include a range of diverse data types such as population data, electrification, appliance ownership, and sectoral breakdown of energy consumption. Data collection and coverage, data gaps, analysis and validation methodologies are covered in detail for each city in the individual modelling reports accompanying the datasets and are referenced in Table 4, and all throughout this work as well.

City	Base year	Grid Emissions Factors (tCO_2/MWh)	Original data source
Dakar	2016	0.648	(Yongoua Nana, Sambou and Nicholson, 2019b)
Cape Town	2018	0.951	(SEA and CoCT, 2015; CCT, 2021)
Nairobi	2016	0.583	(SEA, 2020a)
Yaoundé	2018	0.390	(SEA, 2019d)
Kasese	2016	0.487	(McCall, Stone and Tait, 2017b)
Tsevié	2017	0.638	(SEA, 2019b)

Table 4. Base years and original data sources for studied cities.

Country-level emissions factors were obtained from the Institute for Global Environmental Strategies CDM database (IGES, 2024). All calculations for final energy and GHG emissions were performed using LEAP, which utilises global average conversion factors, and summarized in Table 5. GHG emissions were calculated similarly, utilizing LEAP's IPCC Tier 1 GHG emission database.

Fuel	Calorific Value	Units
Electricity	3.6	MJ/kWh
Paraffin	37	MJ/l
Biogas	25	MJ/m3
LPG	26.7	MJ/l
Charcoal	31	MJ/kg
Wood	13.8	MJ/kg
Diesel	38.1	MJ/l
Oil	37	MJ/l

Table 5. Conversion factors

However, there are notable gaps in these datasets concerning granular information on distribution or consumption patterns across different income brackets. Key data such as electrification rates, household sizes, household incomes, shares of fuel use, and end-use data disaggregated by income quintiles were insufficiently detailed or missing. To fill these data gaps, we made use of several modelling techniques to model the distributions of various data points, based upon available data and described in the following sections.

3.6.1. Data collection and processing

As part of the first phase of the CoMSSA initiative between 2017 to 2020, the author was responsible for building the capacities of municipal staff and civil society organisations on energy and climate action planning in the study cities of Yaoundé, Tsévié and Dakar over the duration of the project. This involved developing the technical requirements and final sign-off of the questionnaires that were used by the cities for field data collection (in the case of Tsévié and Yaoundé) and secondary data collection in the case of Dakar. This approach sits well within the research methods of coproduction of knowledge, in that it hinges on the goal of collaboratively designing the research methodology and to move away from "expert-built" analytical frameworks that may fail to capture local knowledge or management practices (Djenontin and Meadow, 2018). And as Pettigrew (2001: 61) argues, a 'deeper form of research that engages both academics and practitioners is needed to produce knowledge that meets the dual hurdles of relevance and rigor for theory as well as practice'. As such, this collaboration led to the creation of entirely new datasets that did not previously exists or at least, were not previously accessible to municipal staff and data practitioners.

The following section describes how each city's original datasets were processed and transformed to fit the requirements of the UHEM model and how data gaps were filled.

i. Dakar

For Dakar, the author collated and analysed the original dataset for the 2016 base year. This dataset was initially gathered under the C40 CAP Africa program to compile the city's GHG emissions inventory, which totals emissions attributable to activities taking place within the geographic boundary of the city. This detailed inventory can be accessed via C40's online repository (C40, 2022b). Dakar's datasets include data from a variety of secondary sources and interviews, covering sectors like buildings (residential, commercial, industrial), agriculture, transport, waste, and energy production. The methodology and data gaps for this dataset is documented in the respective CAPs and technical annexes (Yongoua Nana, Sambou and Nicholson, 2019).

For this thesis, the author expanded upon the existing activity data to construct detailed energy balances for Dakar as shown in Table 6. However, the initial dataset lacked granularity, especially in the residential sector – for example, data on the quantity of charcoal used by affluent households (Q5) for cooking, or the ownership rates of refrigeration equipment among lower-income households (Q2) etc. To bridge these gaps and align with the UHEM model's requirements (refer to Figure 10), the study made use of several Logit functions to model the distributions across various activity data points and end-uses in Dakar. This modelled data was calibrated using the data available from the original datasets, with the methodology for addressing these data gaps elaborated further in section 3.6.2.

Additional missing points such as GDP, average floor area of households, income distribution across population quintiles, energy requirements for cooling, refrigeration, water heating and cooking needs, and ownership levels of various appliances were collected to augment the dataset. Dakar's key data points are accessible in the online Supplementary Information (SI) file[5]

---

[5] https://figshare.com/s/90a95da8df467a2b7e23

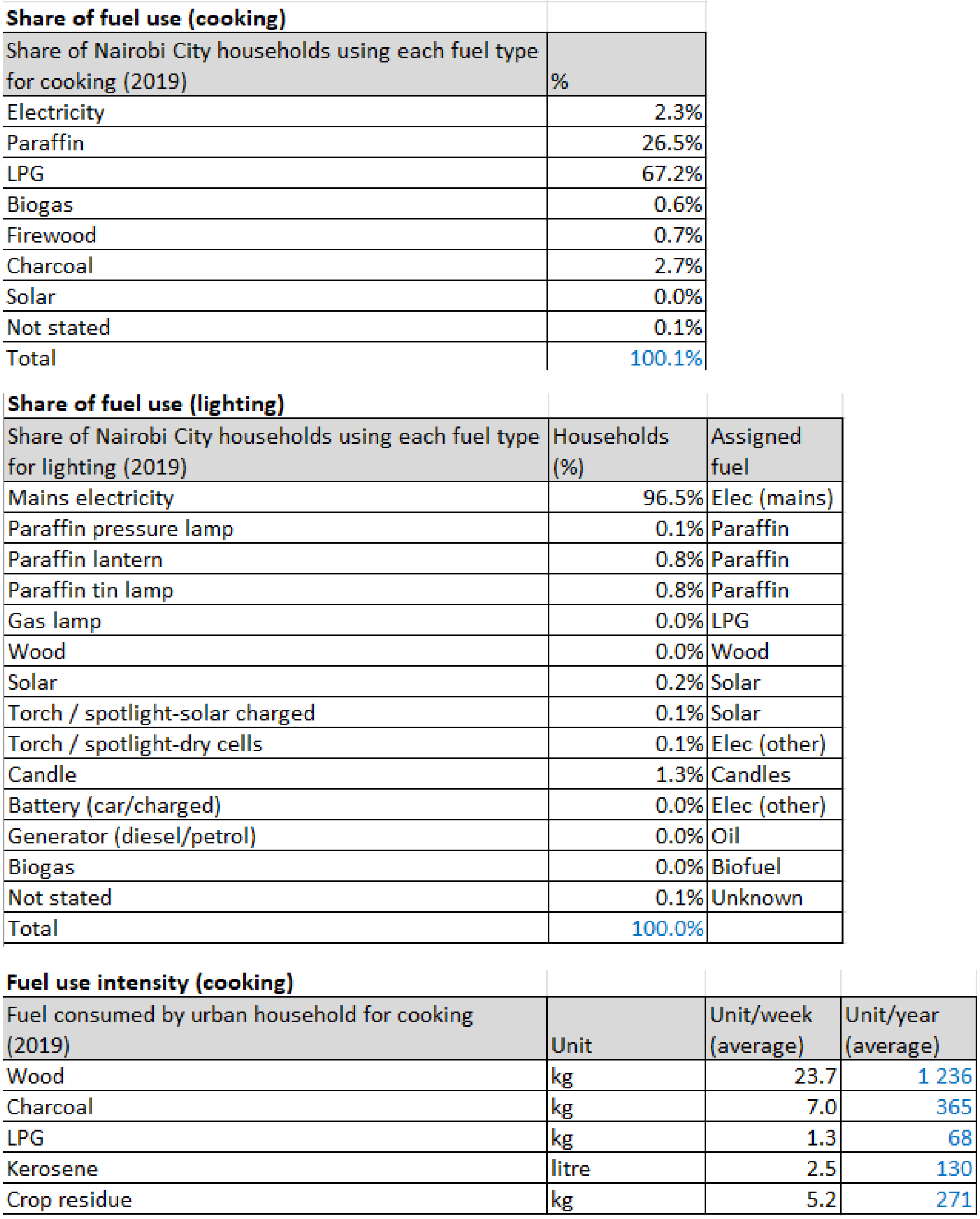
Fuel by sector	GPL	Kérosène	Fioul	Essence	Gasoil	Coal	harbon de bo	ois de chauf	Électricité	Bagasse	
Native units	litre	litre	tonnes	litre	litre	tonnes	kg	kg	MWh	tonnes	
City-induced											
Résidentiel	27 510 347	1 195					23 750 960	25 690 448	179 652		
Commerce/ institutionel	6 284 658				6 483 909				253 667		
Industries/construction	3 942 699		45 504		7 626 937	182 727			836 933	6 755	
Production d'énergie			51 567		274 016						
Agriculture											
Non-specifié											
Transport - routier				56 159 640	342 973 891						
Transport - aviation											
GJ	GPL	Kérosène	Fioul	Essence	Gasoil	Coal	harbon de bo	ois de chauf	Électricité	Bagasse	Total
Conversion unit (GJ/…)	0.0267	0.037	42.28	0.0342	0.0381	24.3	0.031	0.0138	3.6	14	N/A
City-induced											
Résidentiel	734 526	44	0	0	0	0	736 280	354 528	646 748		2 472 127
Commerce/ institutionel	167 800	0	0	0	247 037	0		0	913 202		1 328 039
Industries/construction	105 270	0	1 923 909	0	290 586	4 440 266		0	3 012 957	94 563	9 867 552
Production d'énergie	0	0	2 180 272	0	10 440	0		0	0		2 190 712
Agriculture	0	0	0	0	0	0		0	0		0
Non-specifié	0	0	0	0	0	0		0	0		0
Transport - routier	0	0	0	1 920 660	13 067 305	0		0	0		14 987 965
Transport - aviation	0	0	0	0	0	0		0	0		0
Total	1 007 597	44	4 104 182	1 920 660	13 615 368	4 440 266	736 280	354 528	4 572 907	94 563	30 846 395
Excl. industrial	902 327	44	2 180 272	1 920 660	13 324 782	0	736 280	354 528	1 559 950	0	20 978 843
Emissions (tCO2e)	GPL	Kérosène	Fioul	Essence	Gasoil	Coal	harbon de bo	ois de chauf	Électricité	Bagasse	Total
Conversion unit (tCO2e/native unit)	0.00000	0.00121	3.14428	0.00226	0.00270	1.21019	0.00001	0.00001	0.61400	0.02218	
City-induced											
Résidentiel	0	1	0	0	0	0	141	159	110 306	0	110 608
Commerce/ institutionel	0	0	0	0	17 491	0	0	0	155 752	0	173 242
Industries/construction	0	0	143 077	0	20 574	221 135	0	0	513 877	150	898 813
Production d'énergie	0	0	162 143	0	739	0	0	0	0	0	
Agriculture	0	0	0	0	0	0	0	0	0	0	0
Non-specifié	0	0	0	0	0	0	0	0	0	0	0
émissions fugitive	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Transport - routier	0	0	0	127 148	925 201	0	0	0	0	0	1 052 349
Transport - aviation	0	0	0	0	0	0	0	0	0	0	0
Déchets solide	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	141 090
Eaux usées	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	92 723
Total	0	1	305 220	127 148	964 005	221 135	141	159	779 935	150	2 468 825
Excl. industriel	0	1	162 143	127 148	943 431	0	141	159	266 058	0	1 570 012

Table 6. Summary of Dakar’s 2016 energy balance and GHG inventory.
Note: N/A means not applicable. Source: author’s own analysis

ii. Nairobi

Nairobi’s initial dataset was compiled under the C40 CAP Africa program to build the city’s GHG emissions inventory, focusing on activities within the geographical boundaries of the metropolis. As part of a larger effort across multiple African cities, this dataset aggregated information from secondary sources and interviews on sectors such as residential, commercial, industrial, transport, and waste. While the author’s direct involvement in sourcing and analysing Nairobi’s dataset was limited compared to Dakar’s, the existing records still provided a solid foundation for understanding overall energy consumption patterns.

Despite its breadth, Nairobi’s base dataset required supplementary information to support the more detailed analysis demanded by the UHEM model. In particular, the residential sector lacked sufficient granularity on specific end-uses, such as the quantity of charcoal used across varying income levels and the ownership rates of major appliances among lower-income households. To address these gaps, the study employed Logit functions to distribute and calibrate activity data for different quintiles. Moreover, additional variables – like GDP, average household floor area, income distributions, and energy requirements for cooking, water heating, and refrigeration – were incorporated to create comprehensive energy balances.



Share of fuel use (cooking)

Share of Nairobi City households using each fuel type for cooking (2019)	%
Electricity	2.3%
Paraffin	26.5%
LPG	67.2%
Biogas	0.6%
Firewood	0.7%
Charcoal	2.7%
Solar	0.0%
Not stated	0.1%
Total	100.1%

Share of fuel use (lighting)

Share of Nairobi City households using each fuel type for lighting (2019)	Households (%)	Assigned fuel
Mains electricity	96.5%	Elec (mains)
Paraffin pressure lamp	0.1%	Paraffin
Paraffin lantern	0.8%	Paraffin
Paraffin tin lamp	0.8%	Paraffin
Gas lamp	0.0%	LPG
Wood	0.0%	Wood
Solar	0.2%	Solar
Torch / spotlight-solar charged	0.1%	Solar
Torch / spotlight-dry cells	0.1%	Elec (other)
Candle	1.3%	Candles
Battery (car/charged)	0.0%	Elec (other)
Generator (diesel/petrol)	0.0%	Oil
Biogas	0.0%	Biofuel
Not stated	0.1%	Unknown
Total	100.0%	

Fuel use intensity (cooking)

Fuel consumed by urban household for cooking (2019)	Unit	Unit/week (average)	Unit/year (average)
Wood	kg	23.7	1 236
Charcoal	kg	7.0	365
LPG	kg	1.3	68
Kerosene	litre	2.5	130
Crop residue	kg	5.2	271

Figure 11. Excerpts from Nairobi's raw dataset

iii. Yaoundé

For Yaoundé, the dataset used for this study was collaboratively collected through a field survey conducted with local consultants under the CoMSSA initiative. The author built on this rich primary data to develop Yaoundé's first city-wide energy model, which significantly informed its CAP – see Table 7. The original model was developed using LEAP and included four key sectors: residential, commercial and institutional, industrial, and transport, as illustrated in Figure 12.

Thousand GJ	Tertiary	Industries	Transport	Residential	Total
Candles	-	-	-	0,5	0,5
Electricity	62,5	868,8	-	515,4	1 446,7
Gasoline	-	-	1 202,0	77,5	1 279,5
Kerosene	-	-	-	95,1	95,1

Diesel	-	72,4	1 442,2	3,6	1 518,2
HFO	-	54,3	-	-	54,3
GPL	70,0	4,7	-	1 147,5	1 222,3
Wood	1 495,2	-	-	240,7	1 736,0
Charcoal	29,5	-	-	173,7	203,2
Total	1 657,3	1 000,2	2 644,2	2 254,0	7 555,7

Table 7. Energy balance (Thousand GJ) for Yaoundé in the base year, 2018.
Author's own analysis

The residential sector within the original model was distinctly categorized into electrified and non-electrified households. Electrified households were further segmented into three household bands, namely low, middle, and high income, which in the UHEM model were assumed to correspond to Q1, Q3, and Q5 respectively. This allocation was based on the premise that the original income grouping closely aligned with the income distribution used in the UHEM model. For the electrified households missing data points in Q2 and Q4, the study employed multiple logit functions calibrated to the data from Q1, Q3, and Q5 to estimate these values.

Regarding the non-electrified households, which were initially grouped into a single category, their activity data was assigned to the non-electrified households of Q3 in the UHEM model as a baseline. To fill in the specific data for non-electrified households in Q1, Q2, Q4, and Q5 in the UHEM model, a series of stylized logit functions were applied, again calibrated based on the data associated with Q3. The methodological approach and nature of the modelled logit functions are further described in section 3.6.2.

Additional missing points such as GDP, average floor area of households, income distribution across population quintiles, energy requirements for cooling needs, and ownership levels of various appliances were collected to augment the dataset. Yaoundé's key data points are accessible in the online SI file.

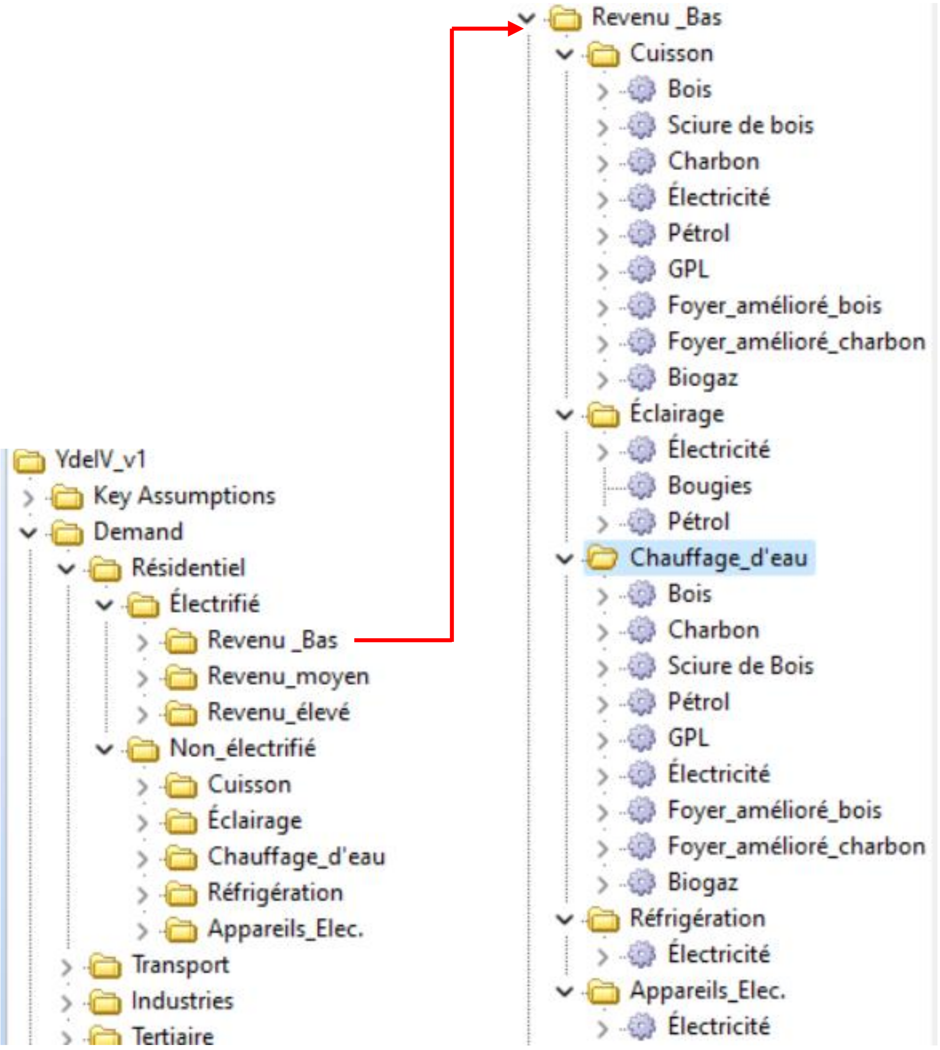
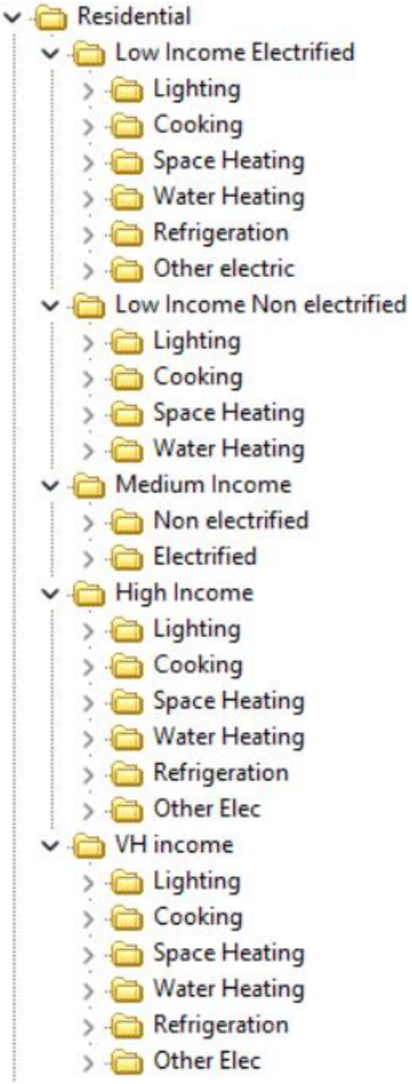


Figure 12. Tree structure of Yaoundé's original LEAP model

iv. Cape Town

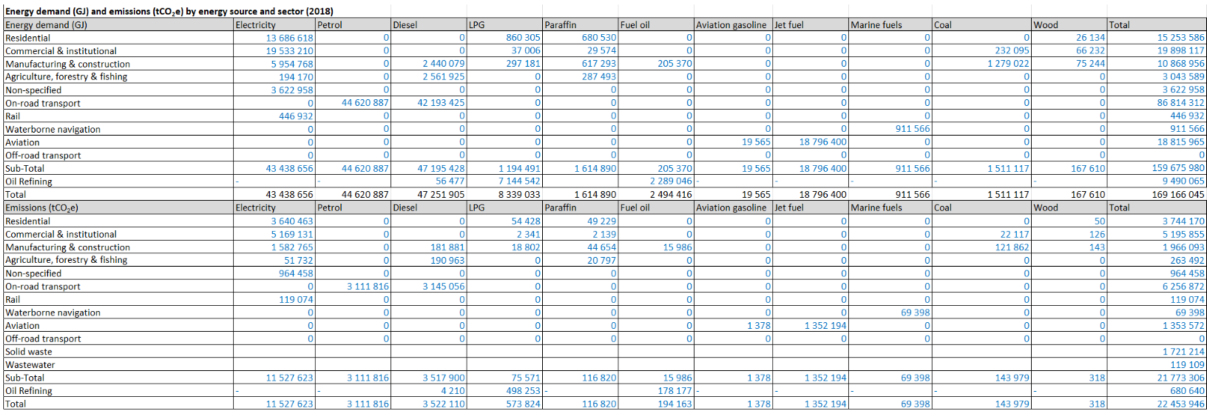
Cape Town's dataset was the most comprehensive and the most compatible with the UHEM model's requirements. The original dataset for Cape Town was initially created to compile the City of Cape Town's first State of Energy report in 2007 (SEA, 2007). Over the years, this dataset has been extensively developed to include detailed data points covering key demand and supply-side sectors.

Particularly notable is the detailed disaggregation within the residential sector, which has been categorized into five distinct household types, comprising both electrified and non-electrified groups, as depicted in Figure 13. This existing categorization greatly facilitated the integration of the dataset with the UHEM model. The dataset was augmented to include missing data points such as to income distribution figures, emissions factors, or activity data related to cooling needs. A summary of Cape Town's key data points is accessible in the online SI file.



- Residential
  - Low Income Electrified
    - Lighting
    - Cooking
    - Space Heating
    - Water Heating
    - Refrigeration
    - Other electric
  - Low Income Non electrified
    - Lighting
    - Cooking
    - Space Heating
    - Water Heating
  - Medium Income
    - Non electrified
    - Electrified
  - High Income
    - Lighting
    - Cooking
    - Space Heating
    - Water Heating
    - Refrigeration
    - Other Elec
  - VH income
    - Lighting
    - Cooking
    - Space Heating
    - Water Heating
    - Refrigeration
    - Other Elec

Figure 13. Tree structure of Cape Town’s original LEAP model for the residential sector



Energy demand (GJ) and emissions (tCO_2e) by energy source and sector (2018)

Energy demand (GJ)	Electricity	Petrol	Diesel	LPG	Paraffin	Fuel oil	Aviation gasoline	Jet fuel	Marine fuels	Coal	Wood	Total
Residential	13 686 618	0	0	860 305	680 530	0	0	0	0	0	26 134	15 253 586
Commercial & institutional	19 533 210	0	0	37 006	29 574	0	0	0	0	232 095	66 232	19 898 117
Manufacturing & construction	5 954 768	0	2 440 079	297 181	617 293	205 370	0	0	0	1 279 022	75 244	10 868 956
Agriculture, forestry & fishing	194 170	0	2 561 925	0	287 493	0	0	0	0	0	0	3 043 589
Non-specified	3 622 958	0	0	0	0	0	0	0	0	0	0	3 622 958
On-road transport	0	44 620 887	42 193 425	0	0	0	0	0	0	0	0	86 814 312
Rail	446 932	0	0	0	0	0	0	0	0	0	0	446 932
Waterborne navigation	0	0	0	0	0	0	0	0	911 566	0	0	911 566
Aviation	0	0	0	0	0	0	19 565	18 796 400	0	0	0	18 815 965
Off-road transport	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total	43 438 656	44 620 887	47 195 428	1 194 491	1 614 890	205 370	19 565	18 796 400	911 566	1 511 117	167 610	159 675 980
Oil Refining	-	-	56 477	7 144 542		2 289 046	-	-	-	-	-	9 490 065
Total	43 438 656	44 620 887	47 251 905	8 339 033	1 614 890	2 494 416	19 565	18 796 400	911 566	1 511 117	167 610	169 166 045
Emissions (tCO_2e)	Electricity	Petrol	Diesel	LPG	Paraffin	Fuel oil	Aviation gasoline	Jet fuel	Marine fuels	Coal	Wood	Total
Residential	3 640 463	0	0	54 428	49 229	0	0	0	0	0	50	3 744 170
Commercial & institutional	5 169 131	0	0	2 341	2 139	0	0	0	0	22 117	126	5 195 855
Manufacturing & construction	1 582 765	0	181 881	18 802	44 654	15 986	0	0	0	121 862	143	1 966 093
Agriculture, forestry & fishing	51 732	0	190 963	0	20 797	0	0	0	0	0	0	263 492
Non-specified	964 458	0	0	0	0	0	0	0	0	0	0	964 458
On-road transport	0	3 111 816	3 145 056	0	0	0	0	0	0	0	0	6 256 872
Rail	119 074	0	0	0	0	0	0	0	0	0	0	119 074
Waterborne navigation	0	0	0	0	0	0	0	0	69 398	0	0	69 398
Aviation	0	0	0	0	0	0	1 378	1 352 194	0	0	0	1 353 572
Off-road transport	0	0	0	0	0	0	0	0	0	0	0	0
Solid waste												1 721 214
Wastewater												119 109
Sub-Total	11 527 623	3 111 816	3 517 900	75 571	116 820	15 986	1 378	1 352 194	69 398	143 979	318	21 773 306
Oil Refining	-	-	4 210	498 253	-	178 177	-	-	-	-	-	680 640
Total	11 527 623	3 111 816	3 522 110	573 824	116 820	194 163	1 378	1 352 194	69 398	143 979	318	22 453 946

Table 8. Summary of Cape Town’s 2018 energy balance and GHG inventory

v. Tsévié

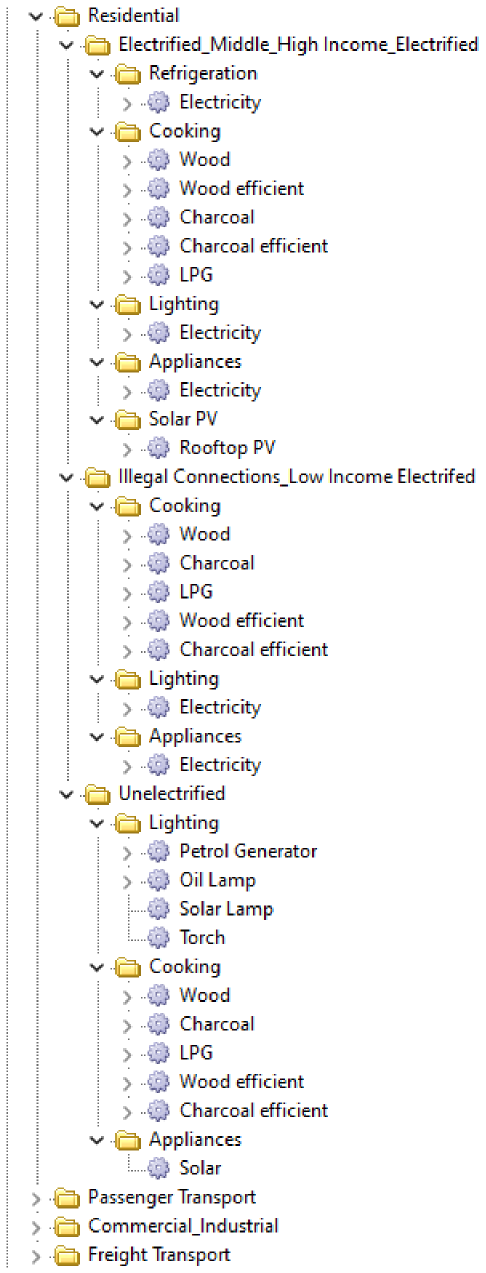
The author played a key role in developing Tsévié’s initial dataset, particularly through designing field survey questionnaires, capacity building of local researchers, and leading the curation of the raw dataset. Collected under the CoMSSA initiative for the 2017 base year, the dataset comprises two primary demand sectors: building (residential, commercial, and industrial) and transport, as shown in Figure 14.

The residential sector in Tsévié’s dataset is categorized into three distinct groups: electrified middle-high income, illegal connections low-income electrified, and non-electrified households. Analysis of the household income data collected from the field survey established that the electrified middle-high income group aligns with the Q3 income level of the UHEM model, while the illegal connections low-income electrified category closely matches the Q1 income level.

To address missing data points for both electrified and non-electrified households in Q2, Q4, and Q5 of the UHEM model, stylized logit functions calibrated based on existing data from Q1 and Q3 were utilized.

Further enhancing the dataset, additional data points were collected on variables such as GDP, average household floor area, income distribution across population quintiles, energy requirements for cooling needs, and ownership levels of various appliances.

The methodological approach and the specific nature of the modelled logit functions are detailed in section 3.6.2. Key data points from Tsévié’s dataset are also made available in an online SI.



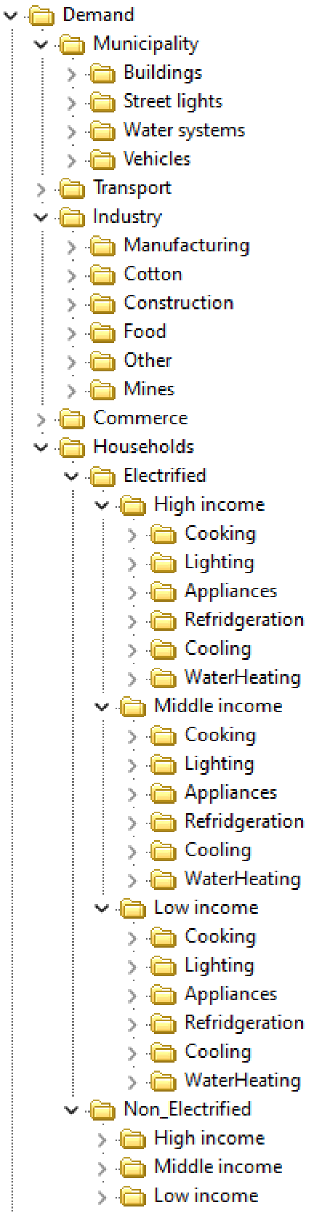
- Residential
  - Electrified_Middle_High Income_Electrified
    - Refrigeration
      - Electricity
    - Cooking
      - Wood
      - Wood efficient
      - Charcoal
      - Charcoal efficient
      - LPG
    - Lighting
      - Electricity
    - Appliances
      - Electricity
    - Solar PV
      - Rooftop PV
  - Illegal Connections_Low Income Electrifed
    - Cooking
      - Wood
      - Charcoal
      - LPG
      - Wood efficient
      - Charcoal efficient
    - Lighting
      - Electricity
    - Appliances
      - Electricity
  - Unelectrified
    - Lighting
      - Petrol Generator
      - Oil Lamp
      - Solar Lamp
      - Torch
    - Cooking
      - Wood
      - Charcoal
      - LPG
      - Wood efficient
      - Charcoal efficient
    - Appliances
      - Solar
- Passenger Transport
- Commercial_Industrial
- Freight Transport

Figure 14. Tree structure of Tsévié’s original LEAP model

vi. Kasese

The foundational dataset for Kasese was established through the SAMSET initiative, encompassing comprehensive sectoral data as illustrated in Figure 15. The residential sector's structure mirrors that of Yaoundé, employing a hierarchical categorization, first differentiated by electrification status, then further disaggregated into three socioeconomic strata (low, middle, and high-income households).

To align this categorization with the UHEM model's quintile-based framework, national income distribution data for Uganda was employed to map these household categories to their corresponding income quintiles. The interpolation of data points for the second (Q2) and fourth (Q4) quintiles was accomplished through various modelling techniques, detailed in Section 3.6.2, ensuring comprehensive coverage across all income segments. For transparency and replication purposes, the complete set of key parameters derived from Kasese's dataset has been made accessible through an online SI file.



- Demand
  - Municipality
    - Buildings
    - Street lights
    - Water systems
    - Vehicles
  - Transport
  - Industry
    - Manufacturing
    - Cotton
    - Construction
    - Food
    - Other
    - Mines
  - Commerce
  - Households
    - Electrified
      - High income
        - Cooking
        - Lighting
        - Appliances
        - Refridgeration
        - Cooling
        - WaterHeating
      - Middle income
        - Cooking
        - Lighting
        - Appliances
        - Refridgeration
        - Cooling
        - WaterHeating
      - Low income
        - Cooking
        - Lighting
        - Appliances
        - Refridgeration
        - Cooling
        - WaterHeating
    - Non_Electrified
      - High income
      - Middle income
      - Low income

Figure 15. Tree structure of Kasese's original LEAP model

3.6.2. Filling data gaps

As highlighted earlier, while the cities' datasets formed the primary foundation for the model-based analysis, they exhibited varying levels of granularity and completeness, necessitating a systematic approach to address data gaps. This section details the methodological framework developed to supplement and harmonize these datasets across all study cities. Several additional data points were collected and proxy indicators developed, including income distribution by quintile, population growth trajectories, residential floor space, and other socioeconomic parameters critical for energy use analysis. To address remaining data gaps, a series of logit models were developed and calibrated to estimate missing values and investigate the sensitivity of key input parameters, such as electrification status and disposable income.

These models not only served to complete the datasets but also provided valuable insights into the relationships between various socioeconomic factors and energy consumption patterns. The following subsections detail the specific approaches employed for different categories of data gaps.

3.6.2.1. Energy demand drivers

Demographic data:

General population data and average household sizes were sourced from the city's datasets, supplemented by national household surveys where available. Average household sizes were specifically attributed to the middle quintile, Q3, while the sizes for other quintiles were estimated using a model developed by Daioglou et al., (2012). This model establishes a dynamic relationship between the variance across quintiles and the average household sizes within each city using the following equation:

$$Q_{i,HHsize} = Q_{av,HHsize} * (1 + \left(a * Q_{av,HHsize} + b\right) * (3 - i)) \tag{8}$$

Where:

- $Q_{i,HHsize}$ is the quintile i household size
- $Q_{av,HHsize}$ is the average city's household size
- a is the gradient across the quintiles and b a constant

For each city, the constants a and b where calibrated to match the existing demographics data. The modelled quintile household sizes are presented in Table 9.

	Dakar	Cape Town	Nairobi	Yaoundé IV	Kasese	Tsevié
Q1	7.8	4.0	3.1	6.5	4.6	7.8
Q2	6.9	3.3	3.0	5.8	4.3	6.9
Q3 (actual data)	6.0	3.6	2.9	5.2	4.0	6.0
Q4	5.1	3.3	2.8	4.6	3.7	5.1
Q5	4.2	3.1	2.7	3.9	3.4	4.2

Table 9. Modelled household size across studied cities in the base year.
Note: Actual data for Q3 and modelled estimates for other quintiles.

Income distribution:

To capture the household income distribution, we drew upon data from the World Inequality Database (Alvaredo *et al.*, 2016), which offers an expansive and accessible repository of information on the global patterns of income and wealth distribution over time. The WID.world dataset combines national accounts and survey, wealth and fiscal data in a systematic manner in order to estimate the full distribution of national income. This provides percentile-level estimates of income, which were further aggregated into quintile-level estimates for the purpose of this study. Depending on the data availability for each country, we used either of the following: average income or wealth between two percentiles (**aptincj992**), income or wealth shares (**sptincj992**), disposable (**sdiinc992j**) or fiscal (**sfiinc992j**) income.

It is worth noting that while national averages from the WID.world data may not precisely mirror the income distribution within the specific cities examined in this study, these nevertheless serve as the best available proxies to facilitate our approximation and analysis of income disparities across distinct quintiles. It is the author's understanding that developing countries most often do not collect sufficiently rich data on household and price levels, meaning that missing values are imputed by making extrapolations relying on data from capital cities and other urban areas.

Consistent with expectations, we observe in Figure 16 considerable income inequalities across all studies, with Gini coefficients generally above 0.50. Cape Town exhibits the highest Gini coefficient of 0.66, consistent with South Africa's well-documented status as one of the most unequal economies globally (Snowball and Fraser, 2018).

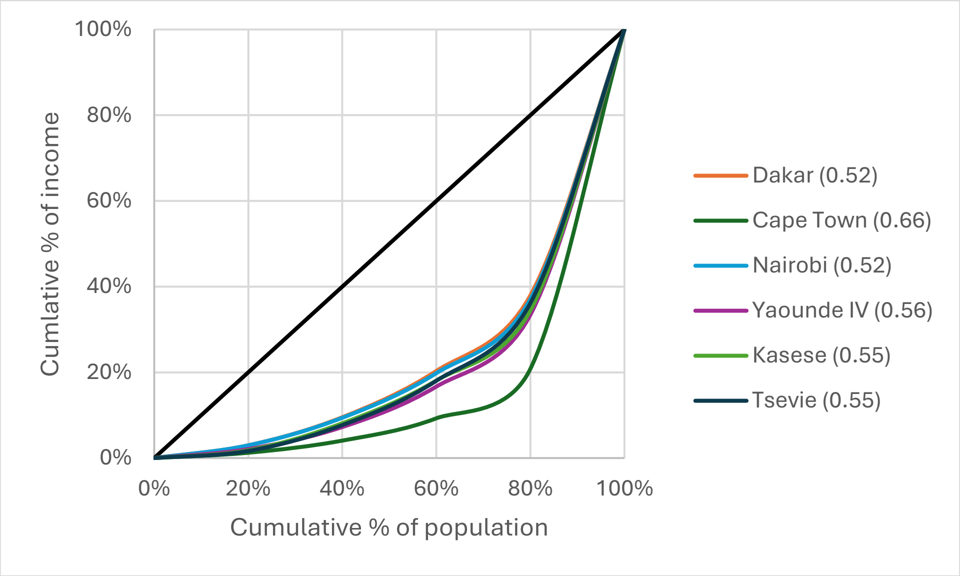


Figure 16. Lorenz curve of household income in the base year.
The diagonal is the line of perfect equality. The numbers presented in parentheses are the Gini coefficients. Author's analysis, based on (Alvaredo *et al.*, 2016).

Electrification:

Data on average electrification rate were obtained from the city's datasets. These averages were attributed to the middle quintile, Q3. To estimate the quintile electrification levels for each city more holistically, we employed a model developed by Daioglou et al., (2012). This model employs a quintile variance approach, characterized by a gradient that extends across the quintiles, in the form:

$$Q_{i,elec} = Q_{3,elec} * \left(1 + \left(-a * Q_{3,elec} + b\right) * (3 - i)\right) \tag{9}$$

Where,

- $Q_{i,elec}$ is the electrification for quintile i
- $Q_{3,elec}$ is the average electrification rate
- a is the gradient across the quintiles and b a constant

For each city, the constants a and b where calibrated to match the existing electricity access data. The modelled quintile electrification levels are presented in Figure 17.

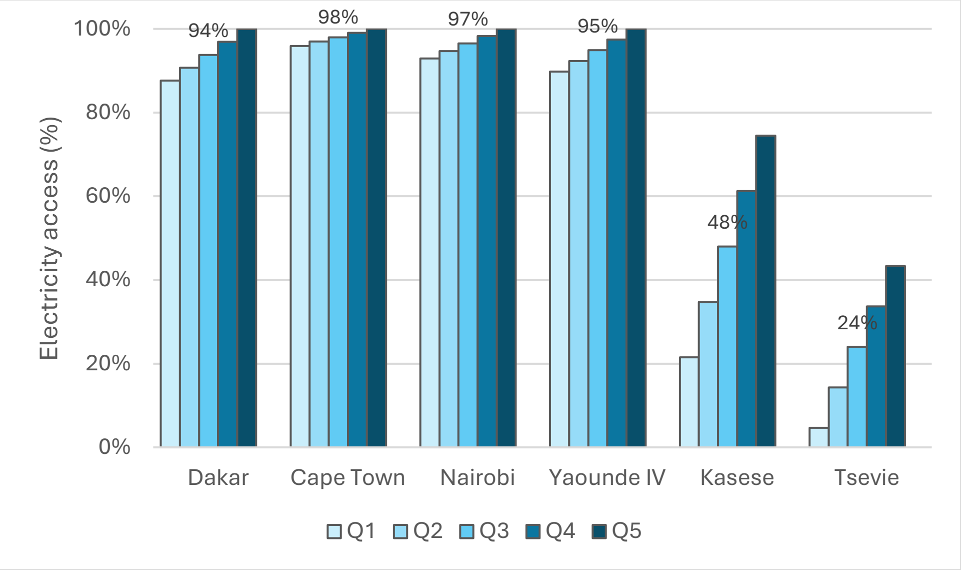


Figure 17. Electricity access across quintiles by city, in the base year.
Note: Actual data for Q3 and modelled estimates for other quintiles.

3.6.2.2. End-uses

Lighting:

Across our examined cities (excluding Cape Town), lighting constitutes a substantial portion of total household electricity consumption, particularly in low-income areas. Primary data from the cities' datasets also indicated the utilization of multiple fuel sources for lighting, including kerosene/oil, solar (including battery-powered torches), LPG, and gasoline/diesel used backup generators. To estimate the final energy demand for lighting across quintiles, we employed a model developed by Daioglou et al., (2012), which models lighting demand as a linear relationship with floor space as follows:

$$E_{l,Qi} = c * Floorspace_{Qi} * LL_{Qav} * LightHours \tag{10}$$

Where:

- $E_{l,Qi}$ the final lighting energy demand for quintile i
- $Floorspace_{Qi}$ is the average floorspace for quintile i
- LL_{av} is the average lighting load
- $LightHours$ is the total light hours computed using the SAIDI index

Cooking:

Although data on cooking energy demand were available for most other cities, it was primarily presented in aggregated form, limiting our ability to gain detailed insights into the relationship between energy use for cooking and increasing affluence. Global cooking data indicate a statistically insignificant connection between income and cooking energy requirement (Daioglou, Ruijven and Vuuren, 2012), with others suggest a range of useful energy demand for cooking between 700 and 900 MJ/capita/year (Ibitoye, 2013). Where data was missing, we made the assumption that individuals across all quintiles have a consistent average useful energy consumption of 800 MJ/cap/year D(Dioha and Kumar, 2020b).

In order to ascertain the distribution of cooking fuels among different income levels, we employed a stylized Gompertz function, represented by equation 11. The parameters 'a', 'b', and 'c' of the function were calibrated to align with the observed market share of the respective cooking technology at the Q3 income level. This calibration process was informed by existing data, desktop research, or national household surveys – all collated data are available on the SI.

$$FS_{Qi,EC} = a * EXP(-EXP(b - b - cQ_{i,inc})) \tag{11}$$

Where:

- FS is the fuel share of each energy carrier for quintile i
- a, b and c are constants calibrated to match existing data

Water heating:

Estimating water heating energy demand presents challenges due to data limitations and the intertwined use of energy for cooking and water heating in most of our studied cities. The distinction between cooking activities and water heating is particularly unclear in cities other than Cape Town, making it necessary to address data gaps creatively. To overcome these limitations, we adopted a bottom-up approach to calculate the useful energy demand for water heating. This involved considering the daily average water consumption and the required temperature change. To account for income disparities, the quintile variance in useful energy demand for water heating (UEW) was determined using a stylized Gompertz function, with calibrated constants a and b to match existing data. All existing water heating related data across the study cities can be found on the SI. Note that in instances where data was unavailable, we assumed that the shares of water heating fuels would mirror the shares of cooking fuels.

Cape Town is not shown in Figure 18as its original dataset already contained comprehensive water heating consumption data disaggregated by income quintiles, making the modelling of quintile variance unnecessary for this city.

$$UEW_{Qi} = a * \left(1 - EXP\left(-b * Q_{i,inc}\right)\right) * 365 \tag{12}$$

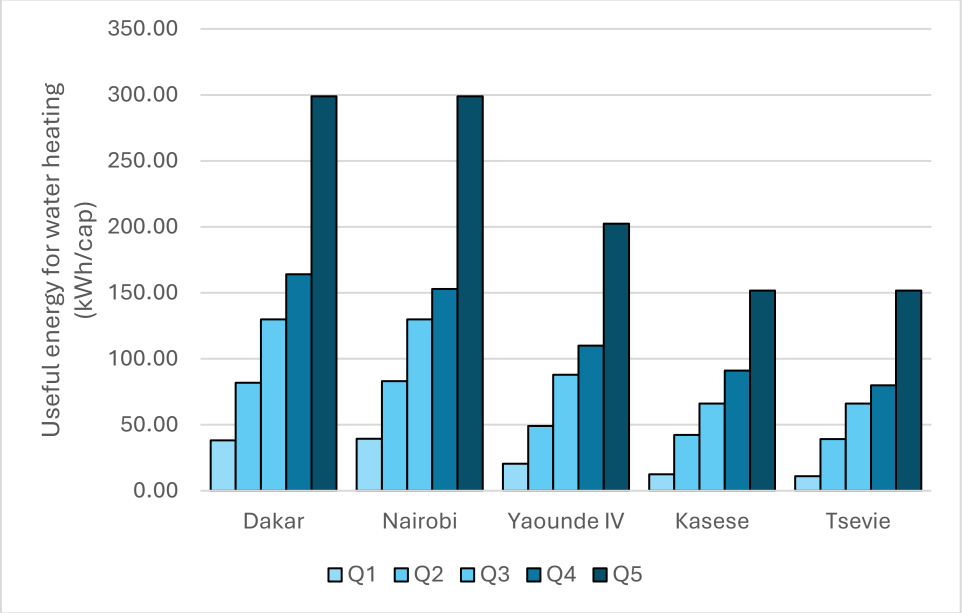


Figure 18. Modelled annual useful energy for water heating by city in their respective base years.

Refrigeration, space cooling/heating and other appliances:

A defining feature of this end-use application is that they rely primarily on electricity. Their load requirements is driven by the level of appliance penetration – a variable shaped by household income levels, adjusted for electrification rate, and compounded by incremental technological efficiency gains across usage cycles. To model the appliance diffusion for each income level, we use a diffusion model developed by McNeil and Letschert (2010) which employs linear regression analysis to parameterize appliance ownership in terms of household income, urbanization and electrification rates according to a standard binary choice (logistic) function – shown below. Model parameters are calibrated from either the available city-level activity data or appliance penetration data from national household surveys all contained in the SI.

$$Diff_{Qi} = \frac{\alpha}{1+\gamma EXP(aQ_{inc}+bElec+cU} + \varepsilon \tag{13}$$

Where:

- $Diff_{Qi}$ is the diffusion of the appliance for quintile i
- α is the saturation level,
- U is the urbanization rate,
- Elec is the electrification rate,
- and ε is the error term

3.6.3. Gini coefficient calculation

The Gini coefficient, first proposed by the statistician and sociologist Corrado Gini, is an internationally recognized measure of income disparity. This metric, along with the Lorentz curve have since then become powerful indicators to measure energy inequality (Jacobson, Milman and Kammen, 2005).

For this study, the Gini coefficient is used to quantify income, energy and emissions inequalities within the cities analysed, with values ranging from 0 (indicating perfect equality) to 1 (representing absolute inequality).

First, as income is a key variable influencing various data points in our analysis, we standardized all income data, for ease of comparison, by converting it to constant 2011 US dollars PPP (i.e. Power Purchase Parity). We computed this using the Local Currency Unit (LCU) conversion factor in PPP and GDP deflators obtained from the World Bank (World Bank, 2019), as follows:

$$Q_{i,inc} = \bar{Q}_i/LCU/GDP\_D/GDP\_D_{2011} \tag{14}$$

Where:

- $Q_{i,inc}$ is the average mean income of quintile i in constant 2011 US$,
- $\bar{Q}_i$ is the base year mean income of in the local currency,
- LCU is the PPP LCU Conversion factor in the base year, and
- GDP_D and GDP_D_{2011} are the USD GDP deflators in the base year and 2011 respectively.

The income Gini index was then calculated using equation 15:

$$G = \sum_{i=1}^{n} P_i \, sQ_{i,inc} + 2 * \sum_{i=1}^{n} P_i \left(1 - \emptyset Q_{i,inc}\right) - 1 \tag{15}$$

Where:

- G refers to Gini index,
- P_i and $sQ_{i,inc}$ are the population and income share of quintile i in each city and
- $\emptyset Q_{i,inc}$ is the cumulative share of the quintile i.

The same method is then applied to calculate the equality status of energy distribution and GHG emissions among households, where income is replaced by energy use or emissions of different income quintiles, by end-use and fuel type.

For the calculation of energy inequalities, this study employs useful energy rather than final energy consumption. This methodological choice reflects the need to accurately capture actual energy services accessed by households, particularly given the significant variations in conversion technology efficiencies across income quintiles in African cities. While final energy represents the total energy delivered to households (e.g., electricity, gas, biomass), useful energy accounts for the efficiency of conversion devices (stoves, heaters, appliances), providing a more precise measure of energy services utilized (Pachauri and Spreng, 2011). This distinction is especially crucial in contexts where lower-income households often rely on less efficient technologies due to affordability constraints, resulting in potentially higher final energy consumption but lower useful energy output. For example, a low-income household using biomass in a 10% efficient stove may consume more final energy than a wealthy household using an 80% efficient electric appliance, while actually obtaining fewer energy services. Using useful energy for Gini coefficient calculations therefore provides a more accurate representation of true energy inequality, avoiding potential misrepresentation that could arise from final energy metrics (Sovacool, 2012) and offering more relevant insights for policy interventions aimed at reducing energy disparities.

3.7. Methods of policy analysis

Evaluation criteria / Sustainability indicators

Core to the policy analysis will be the careful selection of suitable evaluation criteria, measures, or attributes - termed ‘sustainability indicators’ -, mostly informed by the energy system modelling, which will be used to judge the merits of existing strategies/policies and proposed alternatives. More importantly, they are chosen to provide a comprehensive view of the entire energy system, capturing the interconnections and trade-offs among different dimensions of sustainable development as well as the long-term implications of today’s decisions and behaviours. Ultimately, these indicators will address key issues across the economic, social, and environmental pillars of sustainability.

Analysis of existing PAMs

One key component of the research will comprise a qualitative, analytical and descriptive analysis of existing local energy and climate policies / strategies across the selected cities. The analysis will typically utilize the six-step process developed by Patton et al. (Patton, Sawicki and Clark, 2015): (1) problem definition (see above), (2) determination of evaluation criteria (sustainability indicators), (3) identification of alternatives, (4) evaluation of alternatives, (5) comparison of alternatives, and (6) assessment of outcomes.

The aim of this analysis will be to establish the empirical evidence around the alignment (or not) of existing local energy and climate strategies with respect to achieving the common goals of sustainable economic development and an equitable energy transition. This will be key to understanding the linkages between energy and socioeconomic development and how the current structure and governance of urban energy systems actively undermine the poverty and inequality reduction goals of local governments, hence addressing research question 3.

Formulation of alternative PAMs

Following the evaluation of existing policies / strategies and the clear identification of gaps / misalignment with intended development objectives, alternatives will be proposed and assessed against the selected sustainability indicators / evaluation criteria. Central to the formulation of alternative pathways will be sustainability, equity through reduced energy use and GHG emissions inequalities and broader economic empowerment. These alternative development pathways will define a coherent set of future economic and social drivers of the city-scale energy systems.

In summary, this chapter has described the key methodological steps taken to adapt, calibrate, and validate the UHEM model for analysing energy demand and inequalities across diverse urban contexts in sub-Saharan Africa. These methodological foundations – ranging from study area selection to data gap-filling – lay the groundwork for the more detailed model results and analyses presented in Chapter 4,Chapter 5 and Chapter 6.

Chapter 4 : Energy use, GHG emissions and Inequalities in sub-Saharan African cities

It is the aim for this chapter to contribute knowledge to the urban dimension of energy use and greenhouse gas (GHG) emissions, drawing on data from six SSA urban areas. The analysis also utilises Lorenz curves and the Gini coefficient to assess the equality status of energy use, income and associated emissions among household quintiles. While basing an analysis on six cities makes no claim to be representative of all cities in a large and diverse sub-region, this study nonetheless contributes to knowledge by analysing a more comprehensive and detailed group of cities in SSA than has been possible to date. The goals of this chapter are as follows:

- Contribute to the efforts around generating city-wide datasets for SSA cities,
- Highlight detailed sectoral energy use and emission profiles in six SSA cities,
- Quantify and analyse the inequalities of energy use and emissions among households within the studied cities, shedding light on disparities that may inform equity-focused policy measures,
- Undertake a comparative analysis of energy characteristics, trends, and issues across the selected cities.

Unless otherwise indicated, all results in this section are reported for each city's respective base year (see section 3.6), specifically: Dakar (2016), Cape Town (2018), Nairobi (2016), Yaoundé (2018), Kasese (2016), Tsévié (2017).

In addressing these goals, this chapter provides evidence to answer the first two research questions of this thesis: how cities in SSA consume energy and what drives urban energy demand, and what is the status quo of household energy use and GHG emissions inequalities."

4.1. Social, economic and environmental indicators of energy use

In this section, several indicators are discussed that provide benchmarking reference points to help explore some of the interconnections and potential trade-offs among diverse facets of sustainable development in the context SSA cities.

Table 10 summarizes key indicators of energy use for the six study cities, encompassing social, economic, and environmental dimensions. The detailed analysis of these indicators is presented in the following sections.

Table 10. Indicators of energy sustainability for the study cities in the base years indicated

Indicator	Units	Dakar (2016)	Cape Town (2018)	Nairobi (2016)	Yaoundé (2018)	Kasese (2016)	Tsévié (2017)
Social Dimension							
Gini coeff of household energy use		0.27	0.42	0.30	0.42	0.27	0.31
Share of population with electricity	%	94%	98%	97%	95%	48%	24%
Share of biomass in city's total final energy demand	%	0%	4%	3%	26%	66%	72%
Share of electricity in city's total final energy demand	%	30.3%	16.0%	16.7%	19.1%	2.6%	3.0%
Share of biomass in household total final energy demand	%	45%	0%	8%	18%	97%	95%
Share of electricity in household total final energy demand	%	26.0%	91.0%	22.0%	23.0%	2.0%	4.0%
Top 20% (Q5) share of total final household energy use	%	29%	50%	32%	40%	25%	31%
Economic Dimension							
Gini coefficient of income		0.52	0.66	0.52	0.56	0.55	0.55
Final Energy use per capita	GJ/a	23	34	12	10	4	16
Final Energy use per unit of GDP ($million)	GJ/US dollar	4106	3592	3480	5839	29290	8024
Household final energy use ratio between Q5 and Q1		3.34	5.59	2.38	6.71	2.55	4.28
Average electricity consumption per capita	kWh/a	1014	2958	562	507	132	10
Average household electricity consumption	kWh/a	860	3059	351	939	203	177
Environmental Dimension							
Gini coefficient of household GHG emissions		0.41	0.43	0.41	0.47	0.30	0.50
GHG emissions per capita	tCO2e/capita	2.10	4.68	1.20	0.71	1.88	0.24
GHG emissions per unit of GDP ($million)	tCO2e/US dollar	376	495	339	436	3410	459
Top 20% (Q5) share of total household GHG emissions	%	41%	51%	40%	44%	29%	47%
Household GHG emissions ratio between Q5 and Q1		9.54	6.40	5.74	9.79	3.19	12.07

4.1.1. Economic indicators

Figure 19 highlights the important link between energy consumption and economic output, even at a subnational level. It is another reminder that urban residents in SSA cities consume significantly less energy compared to the rest of the world. Energy use per capita across the six studied cities remains well below the world average of 84 GJ, though there is noticeable variation among the cities themselves.

Average final energy use per person in the three large cities (Cape Town, Dakar and Nairobi) is 27 GJ, almost double the average across the remaining cities and one and a half times higher than the SSA average of 17 GJ (IEA, 2019a). This highlights the importance of urban nodes as engines of economic growth, with energy required to drive those engines and as Pachauri (2014b) states "there are no low energy, rich countries" and by implication, no low energy, wealthy cities.

Another observation is that the three largest urban economies – Cape Town, Nairobi and Dakar – exhibit greater efficiency compared to the smaller studied cities, as indicated by their positioning below the correlation line. This may be attributed to the reliance of smaller cities and towns on biomass, which is often used in inefficient forms, as will be elaborated further in the following sections. Further, the energy and emissions intensity indicators from Table 10 reveal important variations in how efficiently cities convert energy use into economic output. Energy intensity (energy use per unit of GDP) ranges from 3,480 GJ/million US$ in Nairobi to a striking 29,290 GJ/million US$ in Kasese, while emissions intensity spans from 339 tCO2e/million US$ in Nairobi to 3,410 tCO2e/million US$ in Kasese. Notably, the three largest economies demonstrate markedly lower energy intensities, averaging around 3,726 GJ/million US$, compared to the smaller cities which show higher values. This pattern once again reaffirms that larger urban economies achieve greater efficiency in converting energy into economic output, likely due to more modern infrastructure, higher electricity access rates, and lower shares of inefficient biomass energy sources.

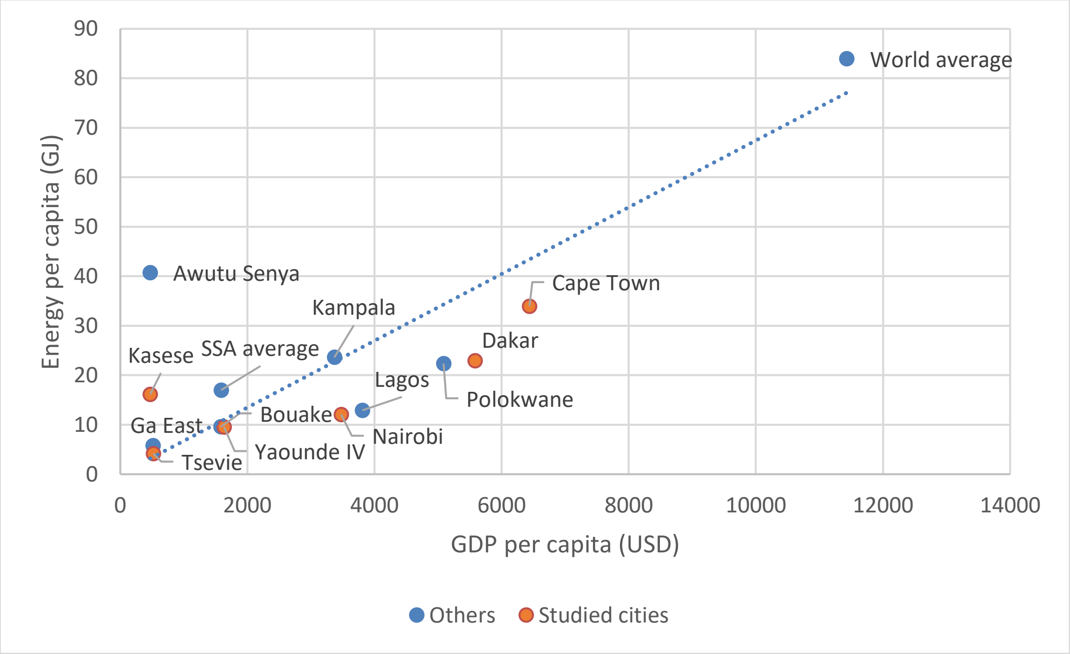


Figure 19. Final energy consumption and GDP per person.
Note: The regression line shown includes the world average data point, which may exaggerate the slope of the relationship.

As above, Figure 20 presents a similar pattern for electricity consumption, which also correlates linearly with GDP, while being significantly below the global average. Average annual per capita electricity consumption (total electricity consumption across all sectors divided by the population) ranges from 10 kWh in Tsévié to 2958 kWh in Cape Town. Cape Town is by far the largest per capita consumer of electricity among the cities studied, owing to a higher purchasing power of the average citizen, high electricity access, a high demand for space and water heating and a significantly higher concentration of commercial and industrial facilities in the city (Ye, Koch and Zhang, 2018; CCT, 2021).

The median electricity use per capita across the study cities is slightly above the SSA's average of 370 kWh, though still much lower than the global average of 3 000 kWh and even more insignificant when compared to OECD and US consumption levels (7992 kWh and 12 573 kWh, respectively) (IEA, 2019a).

These low electricity consumption levels undermine the developmental aspirations of these cities, highlighting the vital role of electricity as a prerequisite for socioeconomic development in the modern era. To reflect Africa's development aspirations for industrialization, employment, higher incomes, prosperity, and economic transformation, the Energy for Growth Hub proposed a modern energy minimum (MEM) of 1000 kWh per capita as a minimum threshold for electricity use to spur competitive economic growth (Moss *et al.*, 2020). Reaching this MEM threshold represents a significant opportunity for four of the six studied cities, which will need to expand their energy systems by between 44% in Nairobi and 9000% in Tsévié to close the electricity consumption gap.

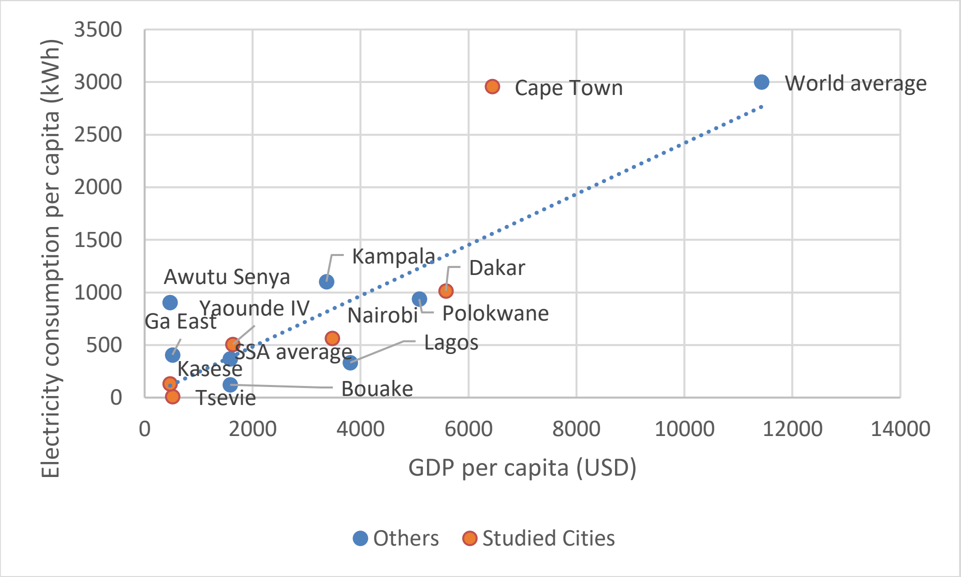


Figure 20. Final electricity consumption and GDP per person.
Note: The regression line shown includes the world average data point, which may exaggerate the slope of the relationship.

4.1.2. Social indicators

Figure 21 provides a nuanced contrast between household energy consumption, GHG emissions, the share of electricity and biomass in total final energy consumption while Figure 22 depicts the distribution of energy use across different income quintiles in the six study cities and a comparison of the Gini coefficients of income, GHG emissions and energy use. The inequalities in energy use are as pronounced within cities as they are between them, revealing disparities that persist at different scales.

The most pronounced disparities are observable in Cape Town and Yaoundé, where household energy consumption and emissions are the most unequal, both with Gini coefficients of energy use of 0.42. In Cape Town, for instance, the wealthiest households (Q5) consumed 8.4 GJ per capita in the base year, 2018 – a substantial contrast to the 1.5 GJ utilized by the poorest quintile (Q1), with the top 20% (Q5) accounting for 50% of total household energy demand, eightfold greater than that of the bottom 20% (Q1), as illustrated in Figure 22.

On the other hand, Kasese and Dakar have the lowest energy use distribution inequalities among the cities studied, with a base year Gini coefficient of energy use at 0.27 - Figure 22. Despite this low inequality in distribution, households in Kasese show high energy intensity, with those in the highest (Q5) and lowest (Q1) income quintiles consuming about 12 GJ and 4.74 GJ per capita, respectively. As shown in greater detail in section 4.2.1, this is largely due to a substantial reliance on biomass in this town, in response to the low levels of electricity access.

Energy use inequalities consistently show lower Gini coefficients than both income and emissions inequalities, being on average 41% lower than income inequalities and 20% lower than emissions inequalities. The average coefficient of energy use is also surprisingly nearly half the global average of 0.58 (Millward-Hopkins and Oswald, 2023), contrary to popular perceptions on the inequalities in Africa. The relatively lower inequality in energy use compared to income also suggests that access to energy functions as a basic need that households prioritize even as other socioeconomic disparities persist.

Notably, there is no clear relationship between the Gini coefficient for energy use and a city's economic output or other key metrics such as electricity access and consumption levels. Instead, each city appears to exhibit a unique energy inequality profile shaped by its specific energy use patterns and economic dynamics.

Another important observation from Figure 21 is that electricity accounts for a mere 3-30% of the total final energy demand within these cities, although the large majority falls under the global average of 20.6%. The share of electricity eventually drops sharply to less than 3% in the small Towns of Tsévié and Kasese, naturally due to lower access rates and smaller electricity demand. As global energy trends pivot towards an 'electricity everything' paradigm, there lies a significant opportunity for social, and technological innovations to shape the transformations needed to electrify these urban economies.

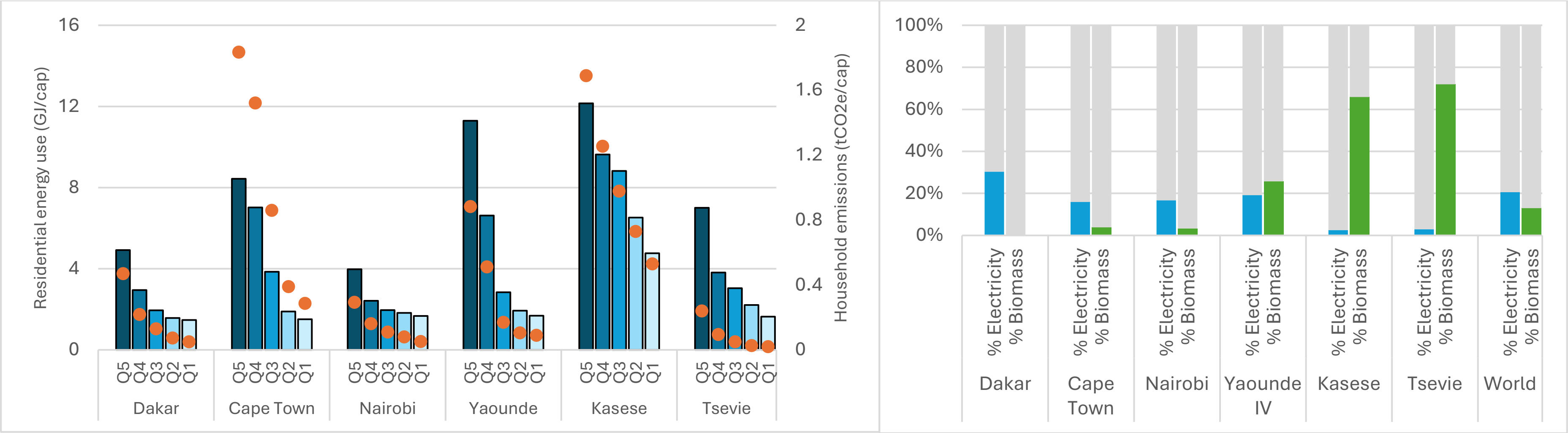


Figure 21. a) Annual residential final energy use and GHG emissions per capita (GJ/cap) by income quintile by city. b) Comparison of shares of electricity and biomass in total citywide energy demand.
Note: Figures for global shares of electricity and biomass were sourced from Popp et al. (2021) and IEA (2024a).

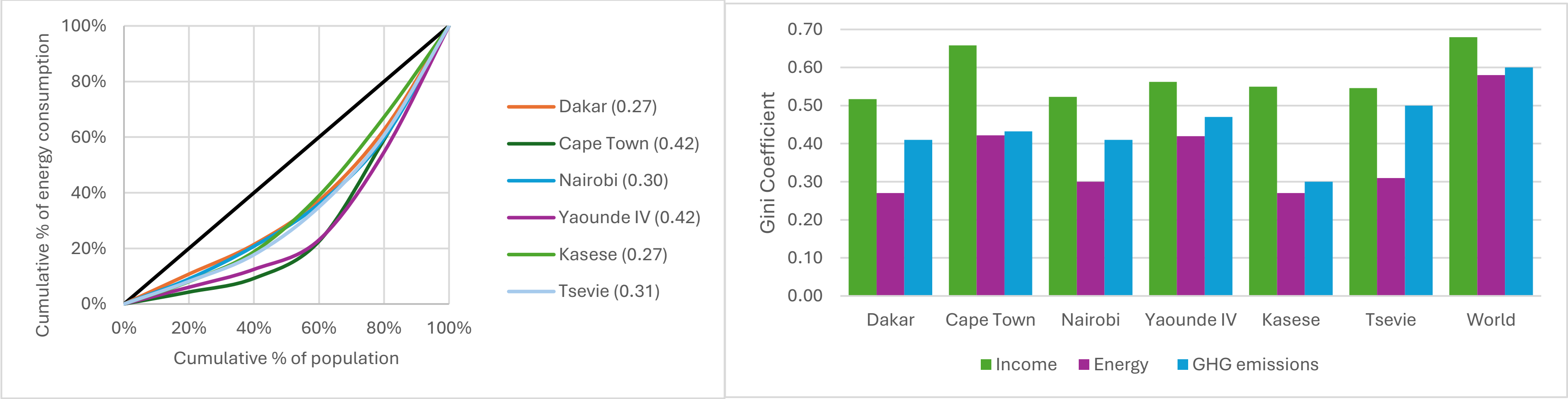


Figure 22. a) Lorenz curves of household energy b) Comparison of Gini coefficients across cities and globally.
Note: The diagonal is the line of perfect equality. The numbers presented in parentheses are the Gini coefficients. All Gini coefficients are calculated using useful energy.

4.1.3. Environmental indicators

Figure 23 shows that GHG emissions per capita are strongly correlated with GDP per capita, mirroring the pattern observed for final energy use. This correlation suggests that economic growth in the studied cities is largely tied to increased fossil fuel combustion, which drives up emissions. Emissions per capita across the study cities vary widely, from as low as 0.2 tCO2e in Tsévié to 4.7 tCO2e in Cape Town, but in general remain below the global average of 4.8 tCO2e per person(World Bank, 2016).

A notable observation is that, despite Cape Town's relatively energy efficient economy (below the correlation line as evidenced in Figure 20 earlier), it stands out for its notably high per capita emissions. This is largely as a result of Cape Town's relatively high electricity consumption in comparison to the ither study cities in addition to South Africa’s power sector being one of the most emissions-intensive in the world. Note however that, while substantial, Cape Town’ emissions per capita is still only half of South Africa's national average (Adeleye *et al.*, 2021).

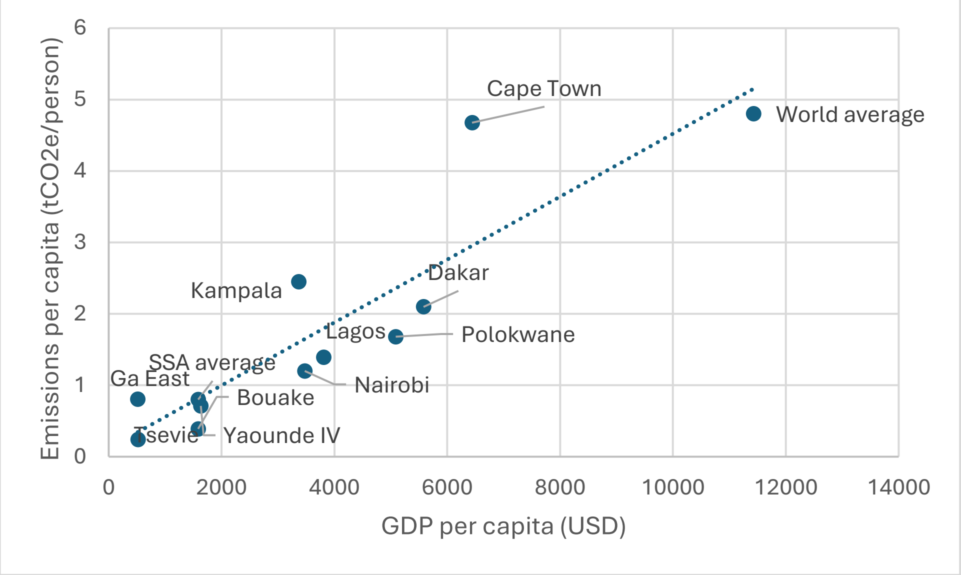


Figure 23. GHG emissions against GDP per capita.
Note: The regression line shown includes the world average data point, which may exaggerate the slope of the relationship.

Figure 24 illustrates the Lorenz curves of household GHG emissions for selected African cities, with the diagonal line representing perfect equality. The disparities in GHG emissions distribution are particularly pronounced in Cape Town, Yaoundé and Tsévié, with Gini coefficients of 0.42, 0.47 and 0.50, respectively. In Cape Town for instance, on average, households in the highest income quintile (Q5) produced 1.83 tCO2e per capita – over six times higher than the emissions generated by households in the lowest quintile (Q1).

Conversely, Kasese exhibits the most equitable distribution of household GHG emissions, with a Gini coefficient of 0.30, which is significantly lower than Cape Town's by approximately 28%. In Kasese, the wealthiest quintile only makes up 29% of total household GHG emissions compared to an average of 45% across the other five cities. This lower inequality is indicative of the relatively uniform use of low-carbon energy sources like biomass, despite the overall higher intensity of energy consumption in the region.

Across all cities analysed, disparities in household emissions were invariably greater than those related to energy use.

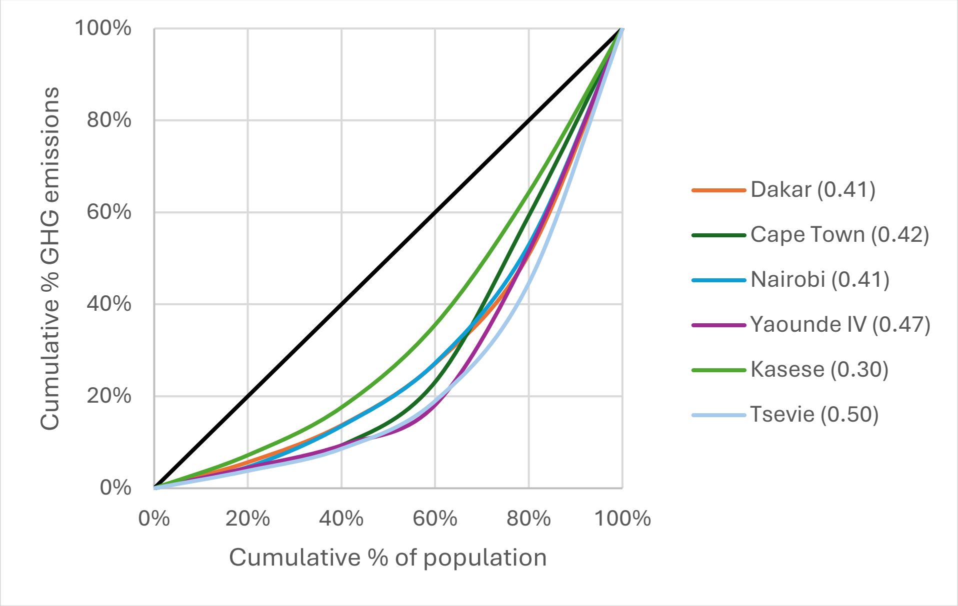


Figure 24. Lorenz curves of household GHG emissions for selected African cities.
The diagonal is the line of perfect equality. The numbers presented in parentheses are the Gini coefficients.

The preceding analysis of key indicators has revealed significant variations in energy use, emissions, and inequalities across the studied cities, highlighting both common challenges and distinct characteristics shaped by local contexts. The following section presents a detailed sectoral analysis of residential, transport, commercial, and industrial energy use and emissions providing insights into how different urban activities contribute to overall energy consumption patterns and associated inequalities observed in the sustainability indicators above.

4.2. Overview of energy demand and GHG emissions

Total final energy demand across the study cities has very marked variations, with Cape Town alone consuming two times more energy than all the other cities combined – Figure 25. Total final consumption is concomitant with population size and economic activities, with energy use per capita generally twice as much in three large economies (Cape Town, Dakar and Nairobi) compared to the remaining cities.

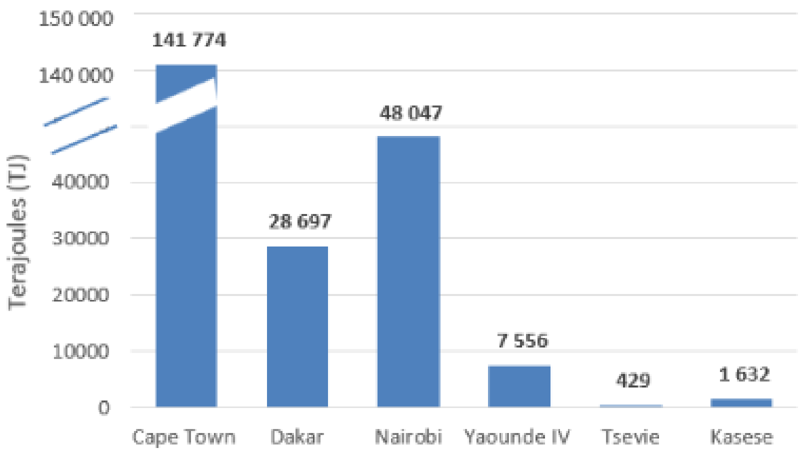


Figure 25. Total final energy consumption by sector by city.

The sectoral energy demand shows predictable patterns across the cities studied, with significant variations tied to city size as illustrated in Figure 26. In the larger economies of Cape Town, Dakar, and Nairobi, the transport sector is a major consumer of energy, accounting for an average of 58% of total final energy demand. This contrasts sharply with smaller cities such as Tsévié and Kasese, where transport's share drops to less than half, reflecting different urban mobility needs and infrastructure.

Conversely, the residential sector is more dominant in smaller cities, contributing to an average of 64% of the final energy demand in Kasese and Tsévié, compared only to 12% in the three large study cities. These figures align a broader trend across SSA, where residential energy consumption accounts for 65% of the total final demand, compared to the global average of 22%.

The shares of energy consumption for productive use (i.e. combining commercia, industrial and agricultural sectors) also varies significantly, with the lowest in Tsévié (3% of total final demand) and highest in Dakar at 39% of total final demand. At the SSA regional level, industrial production only makes up 14% of total energy consumption.

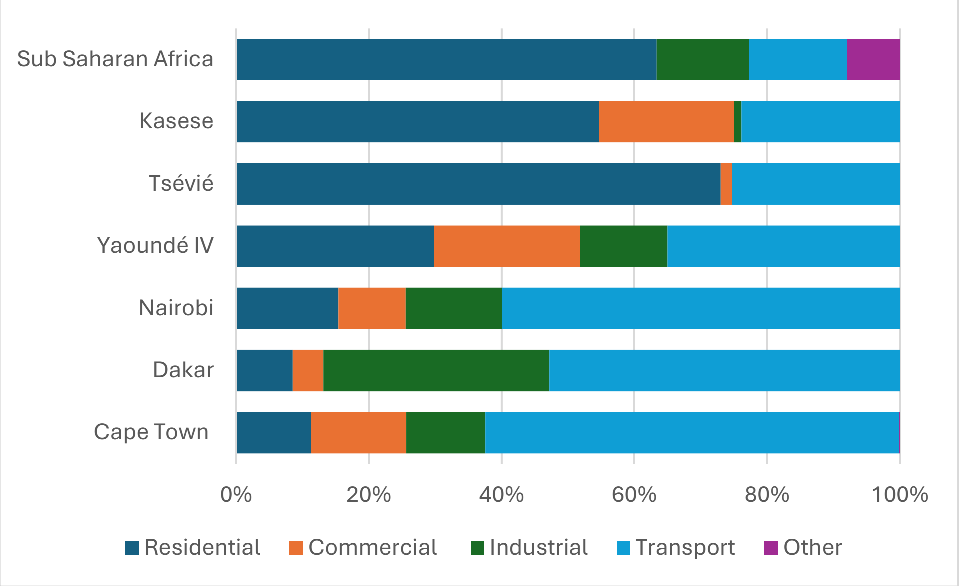


Figure 26. Share of energy use by sector by city.
Note that for SSA, IEA (2019a) combines final energy demand for commercial activities under "Industry"

Figure 27 and Figure 28 present the total greenhouse gas (GHG) emissions for each city along with the distribution of emissions by sector. As anticipated, there is a pronounced variance in total emissions across the study cities, largely aligning with their respective economic outputs. Cape Town stands out markedly, with its emissions substantially exceeding those of the other cities. This notable difference is attributable to South Africa's highly emission-intensive electricity generation, which, in per capita terms, is approximately twice as intense as the average for the world's 20 largest economies– G20 (Climate Transparency, 2018).

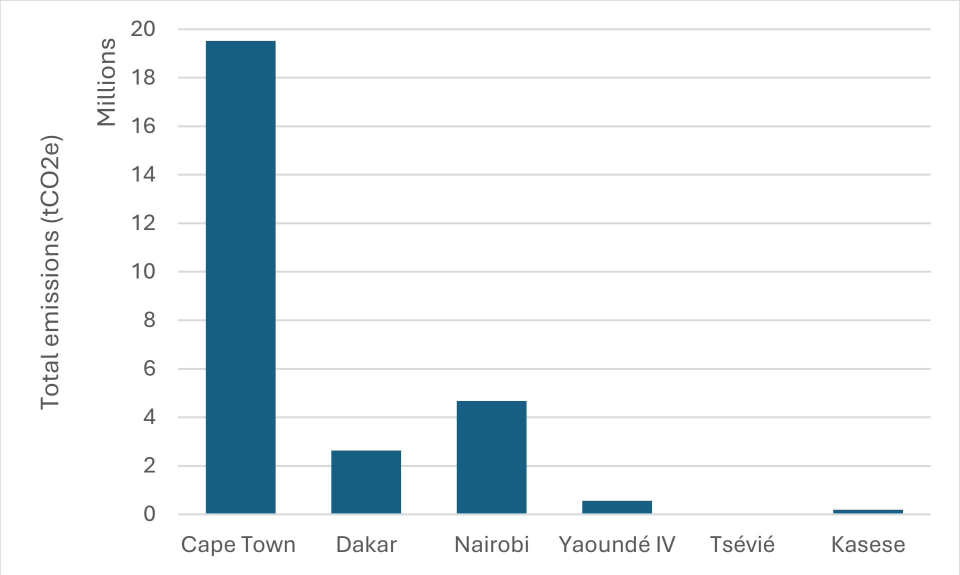


Figure 27. Total urban GHG emissions by city

Sectoral GHG emissions mirror the trends observed in final energy demand, with one significant deviation occurring in Tsévié. In this city, the transport sector accounts for 62% of total GHG emissions, a substantial increase from its 25% share of total final energy demand. This notable shift can be attributed to the sector's high fossil fuel dependency, while the residential sector is heavily reliant on biomass, and therefore less carbon intensive.

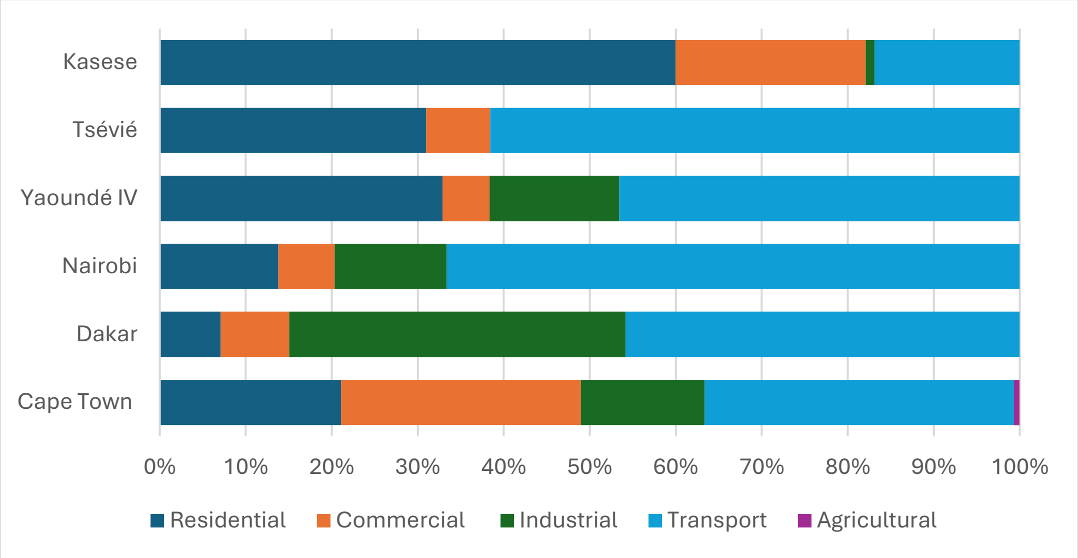


Figure 28. Share of energy-related GHG emissions by sector by city.

4.2.1. Residential energy demand

As seen in Figure 26, household final energy demand generally accounts for a significant share of total energy demand in the small cities. Higher shares of residential energy use point towards low levels of economic activity rather than significant residential consumption. This is the case for the towns of Tsévié and Kasese where a high share of the residential sector energy use is also concomitant with significantly higher shares of biomass, whose predominance is often associated with low levels of industrialization.

Household energy use across the study cities shows great diversity, both in quantity (how much energy is used in total) and specific use (percentages used for different energy services). Energy use per household varies between 4 GJ per household in Tsévié to 34 GJ per household in Cape Town, with household energy use greatly influenced by several factors including location, household size, cooking behaviours, household incomes and living standards, demographics of household members, but also the extent of household reliance on inefficient solid biomass for cooking and poor quality cookstoves (Louw *et al.*, 2008; IEA, 2019a).

Figure 29 illustrates the diversity in residential fuel usage across the study cities, with Cape Town standing out significantly; nearly 90% of its total final household energy demand is supplied by electricity, in contrast to other cities where a broader mix of sources is used. As will be demonstrated in the following sections, household electricity use, more than most other fuels, generally closely tracks economic welfare. The range of annual average household electricity usage variations are quite significant – see section 3.1) varies significantly among the cities studied, from as low as 177 kWh to as high as 3032 kWh and on average 20 times below the 10 972 KWh of electricity used in American households in 2018 (EIA, 2018), and less than half the required minimum level of electricity per household with standard appliances estimated by the IEA at 1,250 kWh (IEA, 2019b). Household electricity use is not always associated with multiplicity of use. As will be show in the following sections, lighting generally account for the bulk of electricity consumption, with slightly higher shares for refrigeration equipment and other appliances only in the secondary and metropolitan cities.

Biomass in the form of wood and charcoal, largely dominates final use in the small cities (Kasese and Tsévié). The use of biomass across all the study cities is almost entirely associated with cooking and water heating activities. The six cities combined are responsible for an annual demand of nearly 102 thousand tons of wood and 60 thousand tons of charcoal, the use of which is associated to household air pollution, which is responsible for many premature deaths across SSA (IEA, 2019a). Furthermore, most of this biomass use is unregulated and not sustainably produced, causing significant forest degradation and—coupled with other land-use changes—deforestation.

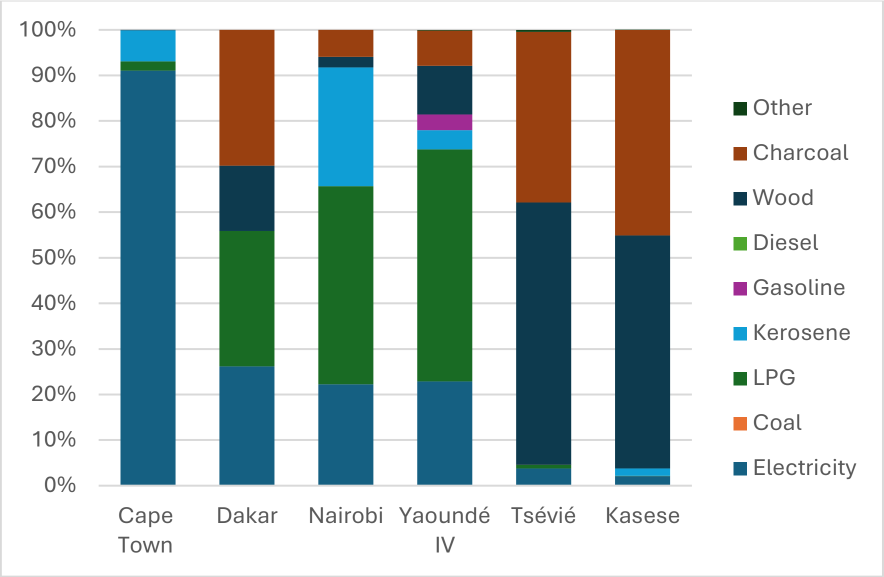


Figure 29. Residential final energy shares across the cities studied

4.2.1.1. Household energy and emissions inequalities by fuel

Figure 30 depicts the quintile variation in the distribution of the share of energy carriers in residential final energy use across the studied cities. More generally, we observe a higher usage of biomass in the lower income quintiles, in contrasts to the proportion of modern fuels, such as LPG and electricity, increasing in the higher income brackets, depicting how economic disparities can lead to exclusion from accessing cleaner fuels.

Unsurprisingly in the smaller towns of Kasese and Tsevié, biomass emerges as a dominant source of household final energy consumption, accounting for a substantial share, exceeding 90%. This is consistent with the extensive literature on household fuel choices in Africa, highlighting the prevalent reliance on traditional biomass fuels for cooking and heating needs (Kojima *et al.*, 2016; Makonese, Ifegbesan and Rampedi, 2018; Puzzolo *et al.*, 2019). Diesel, represented in very small proportions, is indicative of specific niche uses as backup solutions rather than primary energy sources for households. However, the relatively higher shares of diesel use in households in Yaoundé and Tsevié are often linked to low electricity reliability, as evidenced by their relatively high SAIDI System Average Interruption Duration Index (SAIDI) of over 100 hours per year (Ayaburi *et al.*, 2020), prompting some households to adopt diesel as a fallback energy source to cope with frequent or prolonged power outages.

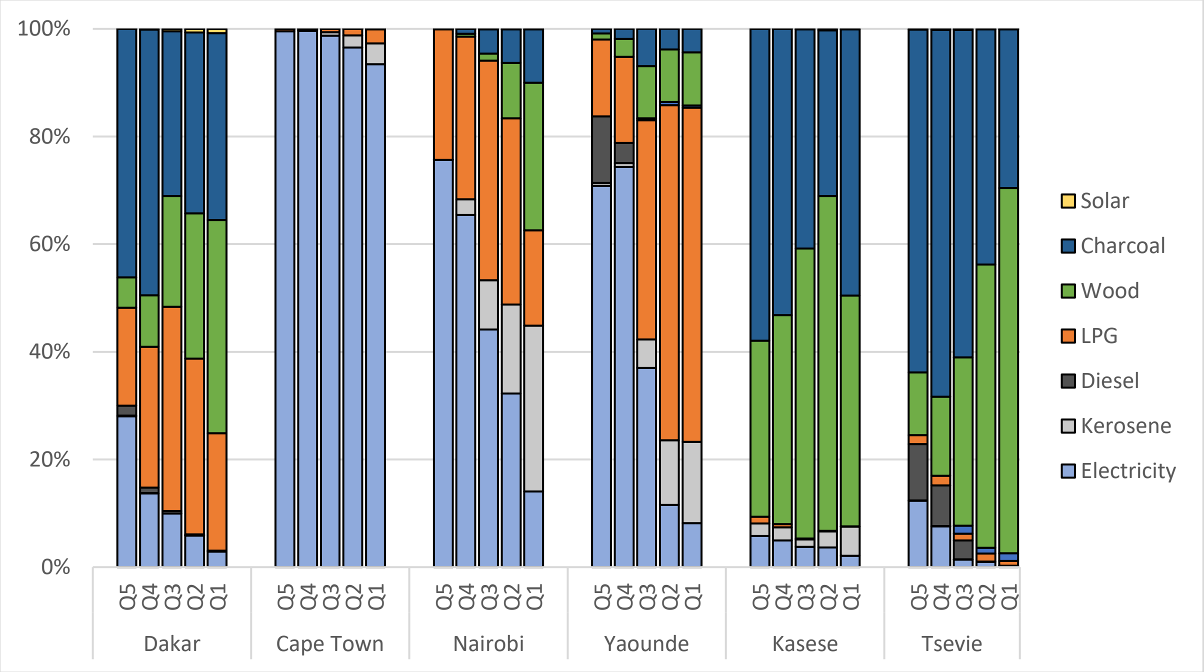


Figure 30. Household final energy share by income quintile for selected African cities.
Note that solar in this case denotes the use of solar lamps as opposed to more sophisticated rooftop solar PV.

Figure 31 provides insights into the distribution and Gini coefficients of different energy carriers for all study cities in their respective base years, showcasing that energy inequality pervades across all energy carriers. While our examination encompasses both energy and GHG emissions inequalities, the subsequent section will focus on the energy component, as the insights gleaned from this analysis are readily transferrable to GHG emissions as well.

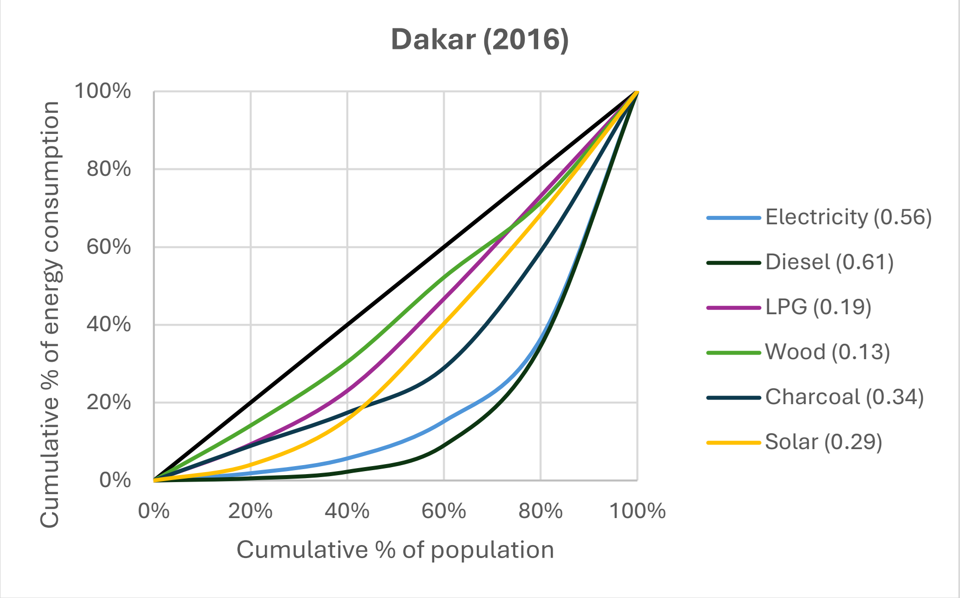
Across the study cities, the Gini coefficient of household electricity consistently ranks among the highest, varying from 0.39 in Kasese to a remarkably high 0.64 in Tsévié. In general, inequality in electricity consumption is much higher than energy use inequalities, but notably for the most unequal cities in terms of income, electricity use inequality is markedly lower. It is worth noting that even in cities with relatively high electricity access rates, such as Dakar, Nairobi, Cape Town and Yaoundé, we still observe high levels of electricity use inequalities. In Dakar for example, despite a high electrification rate that varies from 88% in Q1 to full electrification (100%) Q5, the bottom 20% accounts for only 2% of the city's total final household electricity demand, as opposed to 60% for the top 20%.

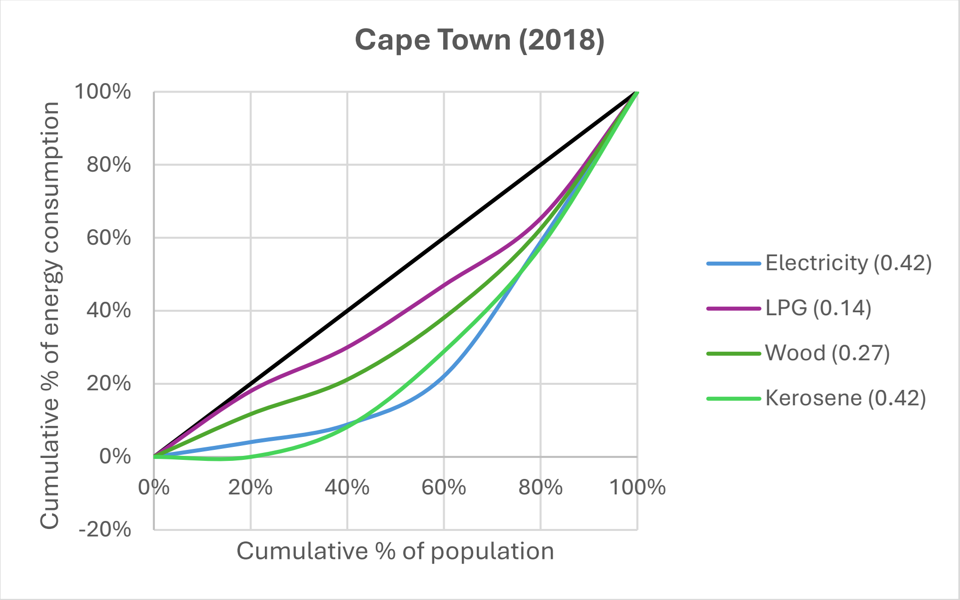
In the cities of Dakar, Yaoundé and Tsévié where diesel is often used in backup generators, as a workaround for the unreliable electricity supply, its distribution use is among the most uneven across all fuel types. This is because diesel generators are predominantly owned by wealthier households that have the means to afford alternative electricity sources.

The reliance on biomass (wood and charcoal) and kerosene in some cases demonstrates a reverse correlation with household income as these fuels are predominantly utilized by the lower-income groups for essential activities such as cooking and lighting. For instance, in Dakar, the lowest income quintile accounts for 30% of the useful energy from wood consumption, increasing to 61% in Nairobi.

Despite the widespread use of biomass (wood and charcoal) among households across the board, even in areas where electricity access is comparatively high, the disparities in biomass consumption among different income levels are sometimes high, with Gini coefficient of charcoal use in Kasese and Tsévié at 0.34 and 0.39 respectively.

Against odds, the analysis also reveals notable inequalities in LPG consumption, particularly in Tsévié (0.38) and Kasese (0.60), despite national subsidies in most of these places aimed at making LPG more accessible and affordable. This suggests that the benefits of fossil fuel subsidies may not always be equitably reaching the poorer segments of the population, but disproportionately favouring wealthier households instead. This observation aligns with existing research, which critiques the efficacy of fossil fuel subsidies in promoting affordable energy access (Soile and Mu, 2015; Taylor, 2020).





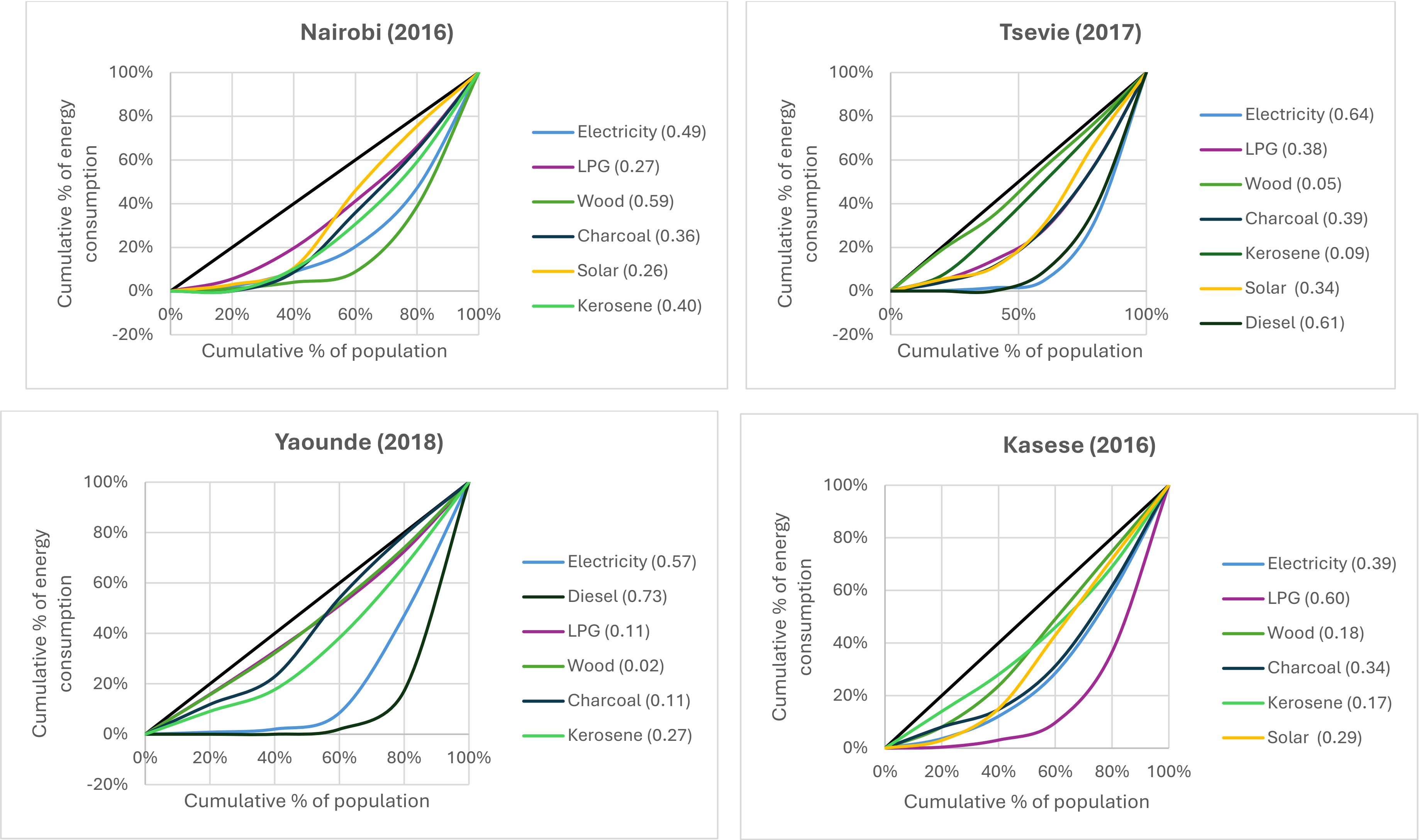


Figure 31. Lorenz curves of household useful energy consumption by energy carriers for the study cities.
Note: The diagonal is the line of perfect equality. The numbers presented in parentheses are the Gini coefficients. All Gini coefficients are calculated using useful energy.

4.2.1.2. Household energy and emissions inequalities by end-use

Figure 32 on the other hand depicts the quintile variation in the distribution of different end-use services in residential final energy use across the studied cities. Cooking shares of household energy budget consistently, with just one exception, increase in lower income quintiles across all cities. As indicated in Figure 30 above, this trend is associated with a corresponding increased reliance on more energy intensive fuels (such as biomass) and subsequently less efficient cooking technologies in contrast to cooking activities in Q4 and Q5 usually having higher shares of electricity and LPG use.

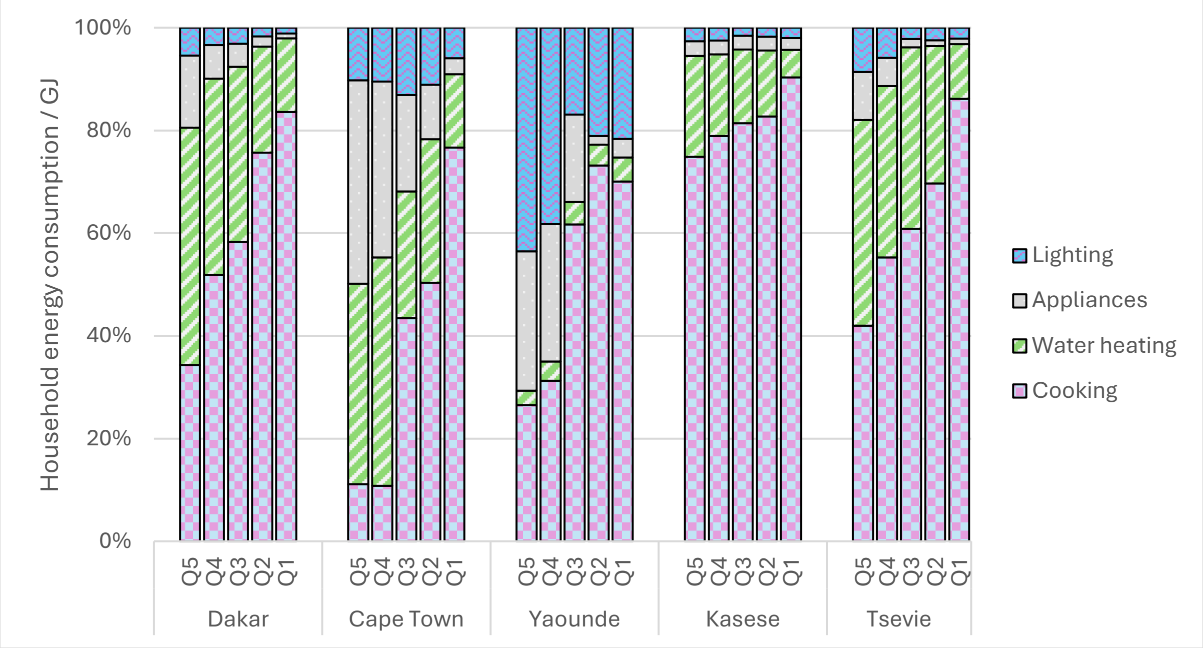
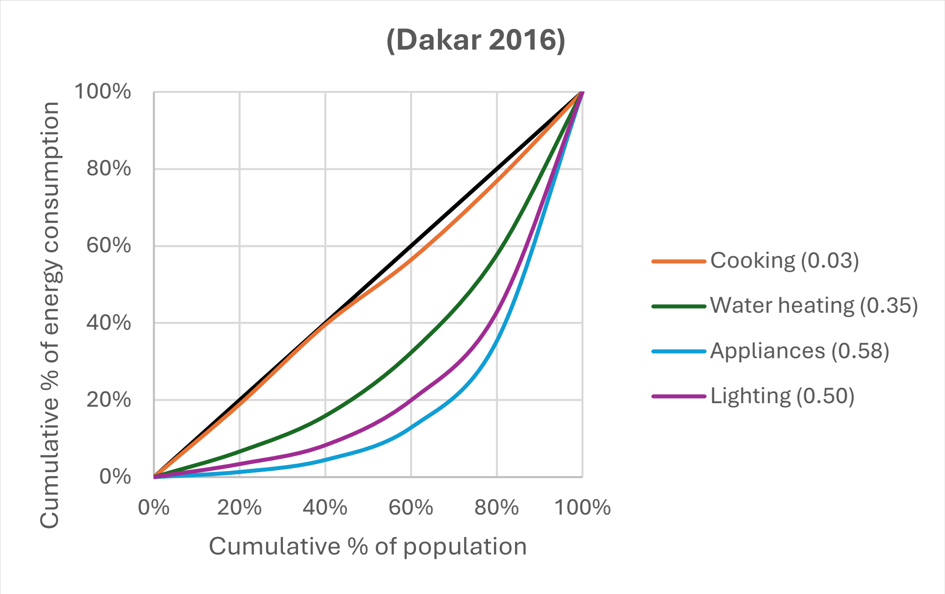


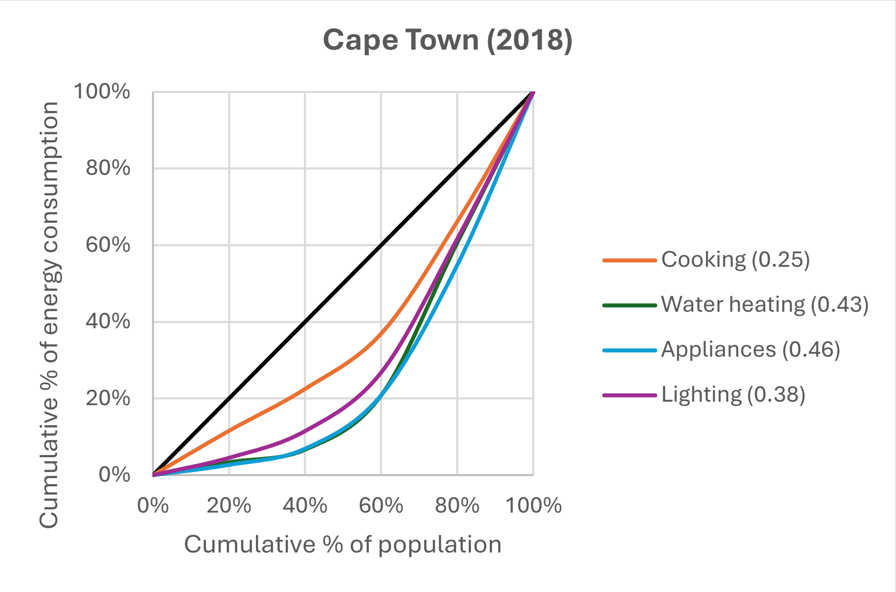
Figure 32. Household final energy share by end-use by income quintile for selected African cities.
Note: Note that the category 'Appliances' combines energy use across refrigeration, cooling, space heating and other appliances

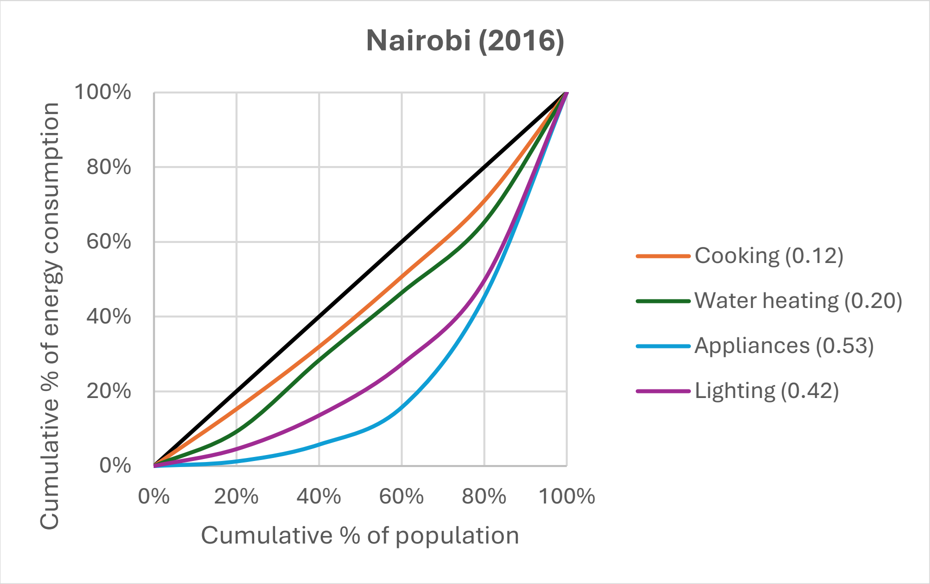
Similarly, Figure 33 showcases the Lorenz curve, offering insights into the energy consumption patterns by end-use activities. Building upon the analysis of inequality distribution by fuel type in the previous section, the analysis reveals that household energy use inequalities equally pervades across all end-uses.

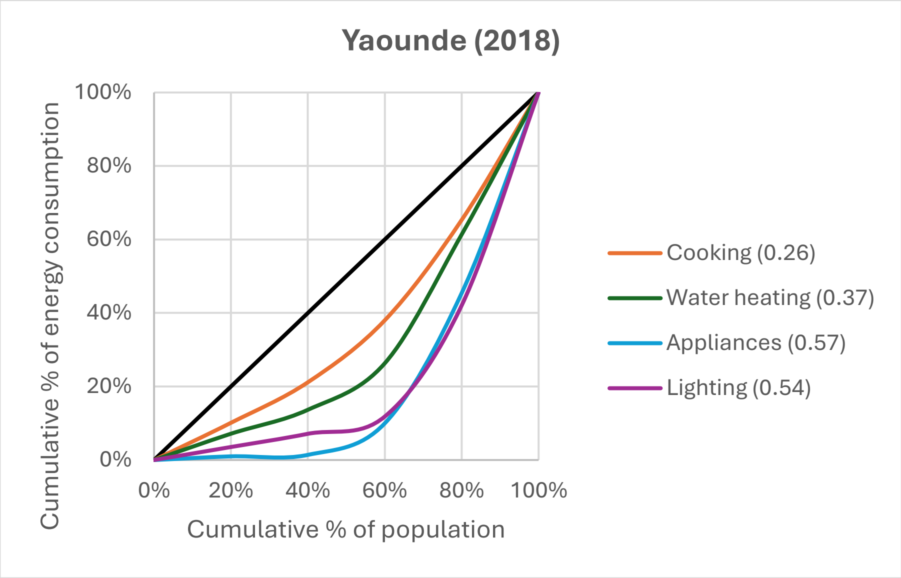
Household energy consumption for appliances – including space heating, cooling, refrigeration, and electronics like TVs – exhibits the greatest degree of inequality, as reflected in Gini coefficients spanning from 0.38 in Kasese up to 0.65 in Tsévié. These inequalities are reflective of, and consistent with, the household electricity use patterns detailed in section 4.2.1.1. which is to be expected given that these applications are heavily reliant on electricity.

Among all the end-use categories examined, the town of Tsévié stands out as the setting with the most pronounced disparities. It is worth noting that Tsévié also has the lowest level of electrification among the six study cities, with an average electricity access rate of merely 24%, which may be linked to this significant variation in energy use across income quintiles. It is also notable to find that cooking activities are the most unequal in Tsévié and Kasese, the two towns among the study cities with the highest reliance on biomass.


(Dakar 2016)
Cumulative % of energy consumption
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative % of population
Cooking (0.03)
Water heating (0.35)
Appliances (0.58)
Lighting (0.50)


Cape Town (2018)
Cumulative % of energy consumption
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative % of population
Cooking (0.25)
Water heating (0.43)
Appliances (0.46)
Lighting (0.38)


Nairobi (2016)
Cumulative % of energy consumption
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative % of population
Cooking (0.12)
Water heating (0.20)
Appliances (0.53)
Lighting (0.42)


Yaounde (2018)
Cumulative % of energy consumption
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative % of population
Cooking (0.26)
Water heating (0.37)
Appliances (0.57)
Lighting (0.54)

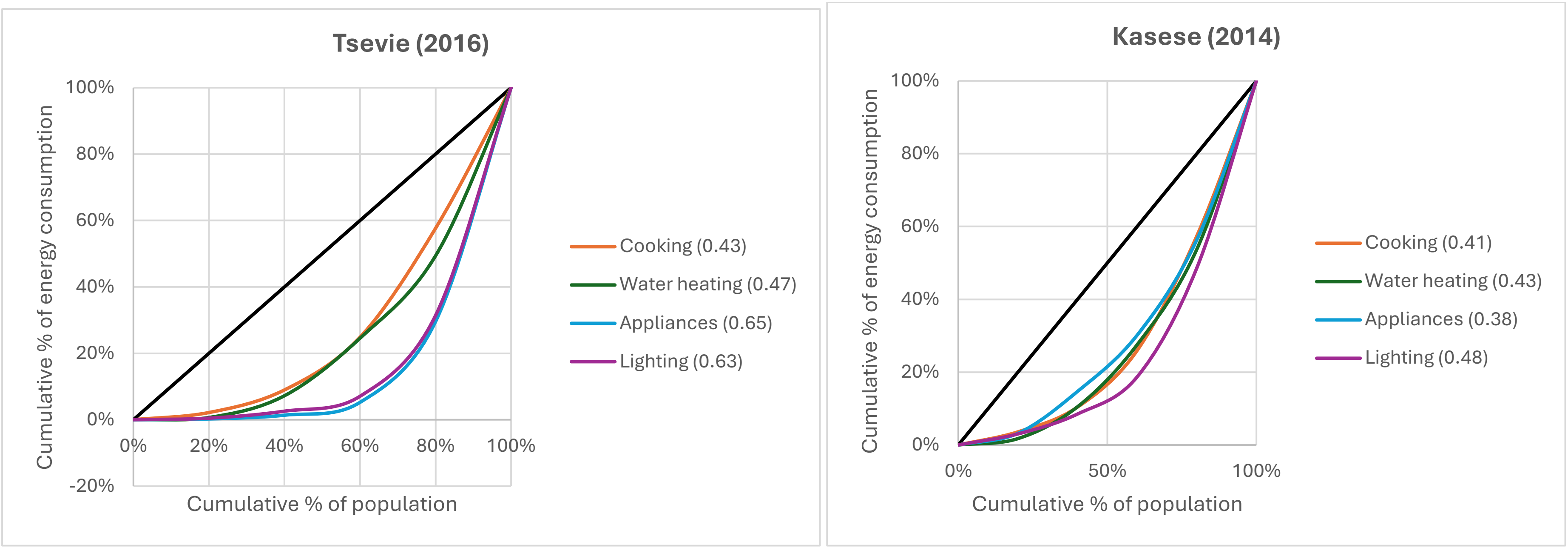


Figure 33. Lorenz curves of household energy consumption by end-use for the study cities.

Note: The diagonal is the line of perfect equality. The numbers presented in parentheses are the Gini coefficients. All Gini coefficients are calculated using useful energy.

4.2.2. Transport energy demand

As highlighted earlier, the transport sector dominates the final energy demand in large urban economies (Cape Town, Nairobi and Dakar), in a manner usually proportional to economic activities (measured in GDP per capita). On one hand, the dominance of the transport sector in these economies is as a result of the greater economic activity, a wealthier populace (greater car ownership) and a substantial transport infrastructure (SEA, 2015c). This correlation is partially captured in figure 7, with transport demand generally tracking the economy, though other factor also seem at play as evidence by the relatively low transport energy use in Dakar and Yaoundé IV. On the other hand, 80% of cars for personal transport in the region consists of over-aged vehicles from Europe and North America which most often have poor emissions ratings and no longer meet standards in their countries of origin, and are much less fuel efficient (Amegah and Agyei-Mensah, 2017; IEA, 2019a). Over-aged vehicle fleets are also major source of air pollution in SSA, accounting for 90% of urban air pollution (Amegah and Agyei-Mensah, 2017).

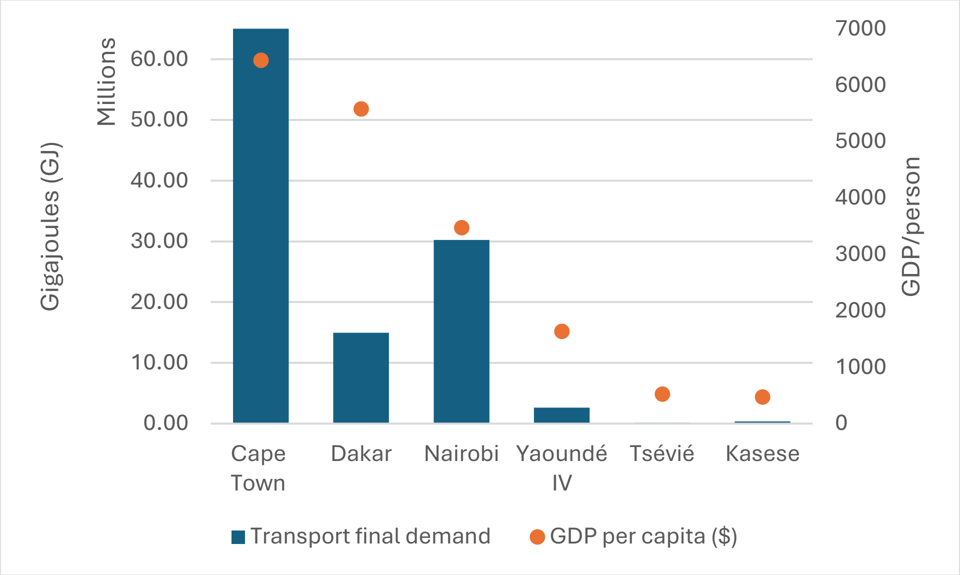


Figure 34. Transport final energy demand against GDP.

The transport sector is characterized by a strikingly high modal share of public and paratransit transport across all the study cities (with informal public transport the most prevalent mode) – Figure 35. Several factors account for the prevalence of informal public transport in SSA cities including: rapid population growth without sufficient expansion of transport infrastructure and services; uncontrolled urban sprawl reducing the viability of public and non-motorized transport; increase in urban population combined with income growth resulting in higher private vehicle ownership and use; or simply the urban infrastructure (roads and streets, sewers and water, electricity, etc.) deficiencies making it difficult for conventional public transport to serve the public (Kumar, Zimmerman and Arroyo-Arroyo, 2021).

Public transport (heavily dominated by minibus and motorbikes in some instances) accounts for approximately 45 – 93 percent of all motorized passenger transport kilometres travelled and is much less energy intensive (on a GJ per km basis) compared to private means of transport. For some cities like Dakar, however, caution should be used in the interpretation of the results due to inaccuracies and inconsistencies in local transport data. For example, Dakar's relatively high share of the private transport is primarily linked to inaccuracies in capturing real vehicle population data. This is linked to the fact that many people living outside the city prefer to have their cars registered in Dakar as it is quicker than anywhere else, therefore resulting in Dakar's private vehicle database being overstated.

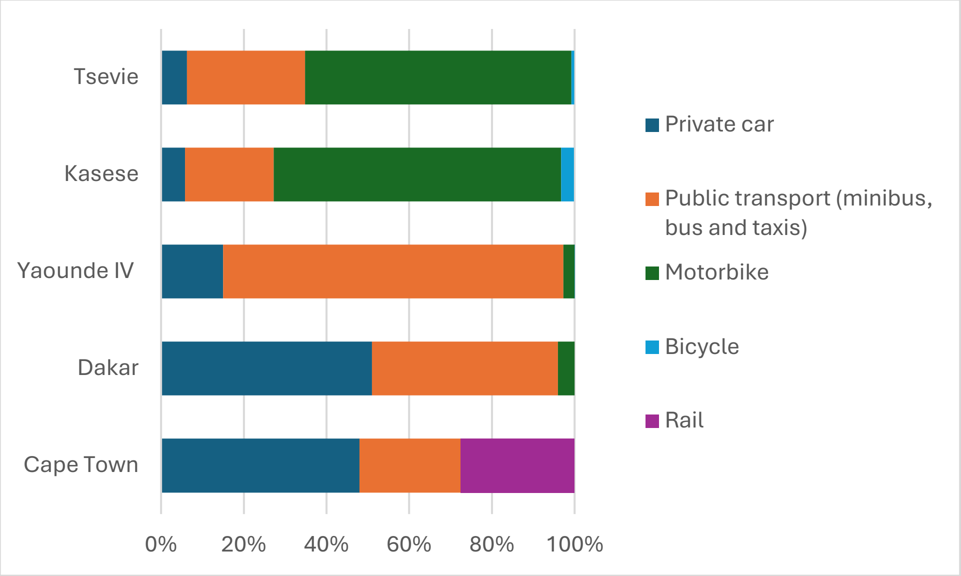


Figure 35. Modal share of passenger transport for selected cities.
Note that Kasese, Yaoundé and Tsévié have very high motorcycle population that is difficult to distinguish as private or public.

4.2.3. Commercial energy demand

Understanding energy use in the business sectors, notably the commercial/service and industrial sectors, remains a great challenge due to lack of data as a result of a lack of funding and research capacity. However, while better data on the commercial use of energy is still being developed, important insights can be made from the existing data presented in this analysis.

Figure 36 stresses the role of economic output (on a GDP per capita basis) in driving commercial use of energy. This is expected given economic growth causes expansion in commercial activities, and therefore higher energy use in this sector. A key observation, however, is the low energy use in the commercial sector compared to world average, suggesting low levels of industrialisation and indicative of the early stage of economic development of these urban centres.

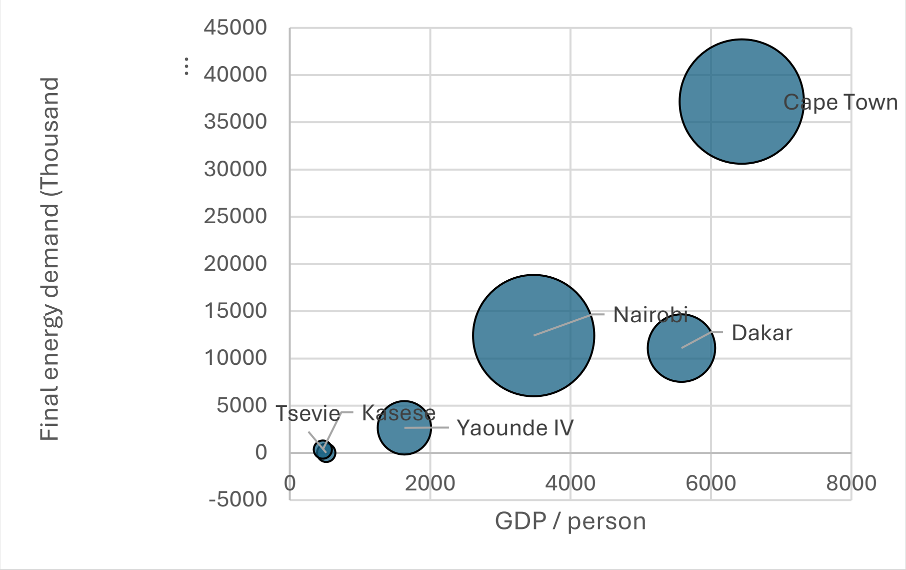


Figure 36. Commercial final energy demand and GDP per person.
Note: Bubble size represents population size.

Figure 37 reveals multiple use of fuels in the commercial sector. Biomass (mainly wood and charcoal) is largely dominant in the Yaoundé, Tsévié and Kasese, accounting for up to 80-96% of commercial use of energy, primarily due to limited choice and access to other fuels. A similar analysis conducted by the Africa Energy Commission (AFREC, 2022) shows that biomass accounted for 62% of the region's commercial sector's energy use in 2017. Wood and charcoal are generally used to provide heat for cooking and heating water. In Cape Town and Nairobi however, electricity is the most widely used source of energy in the commercial sector, most likely emphasising once more the underlying link between the type of fuel use and the level of economic development.

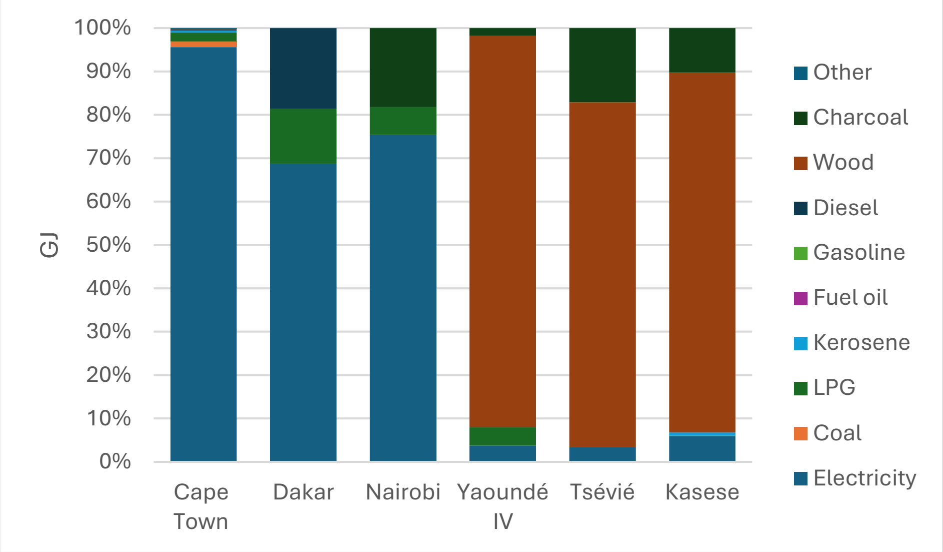


Figure 37. Commercial Final Energy Share by city

4.2.4. Industrial energy demand

Energy use in industrial activities exhibits similar patterns to those in the commercial sector, though there are distinct differences in fuel mix. In the industrial sectors of Yaoundé and Kasese, electricity constitutes a significantly larger portion of the total industry energy demand, while in larger urban economies like Cape Town, Nairobi, and Dakar, this share decreases to less than 35% - Figure 39. This variation is largely due to the nature of the industrial activities prevalent in these cities, where industries in Cape Town, Nairobi, and Dakar are more energy-intensive, often involving processes such as heating that are challenging to electrify efficiently.

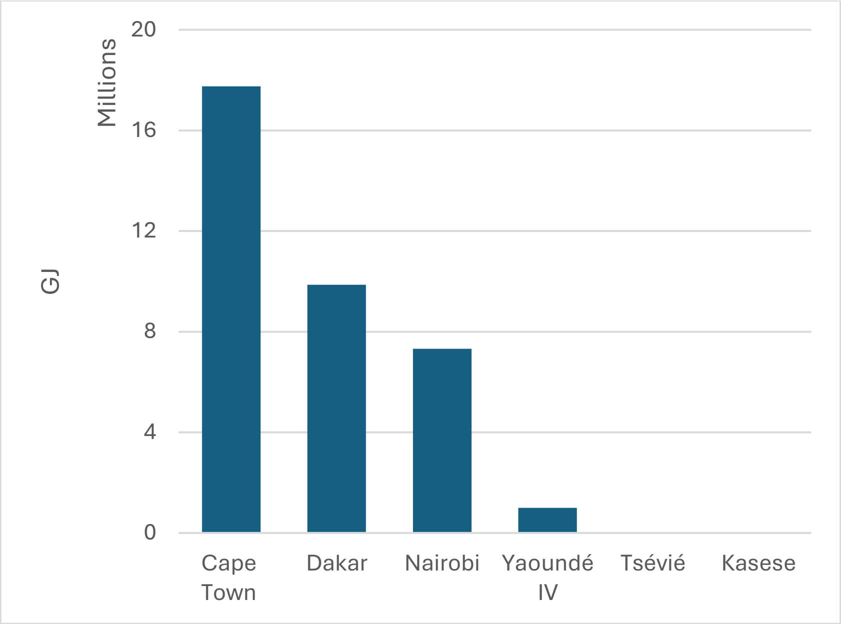


Figure 38. Industrial final energy demand

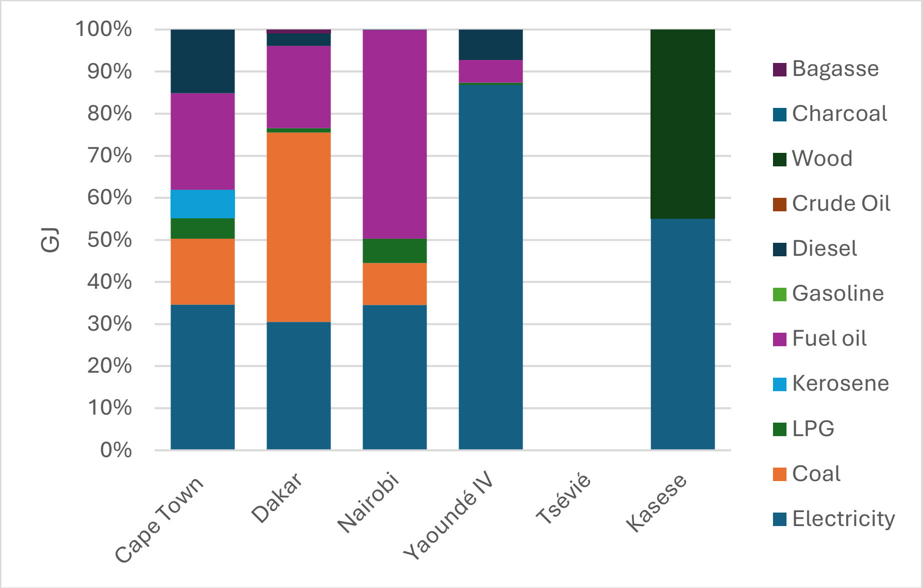


Figure 39. Industrial final energy share by city.
Note: Tsévié has no industrial activity

4.3. Summary of findings of Chapter 4

This chapter has presented a detailed analysis of energy use patterns, greenhouse gas emissions, and associated inequalities across six Sub-Saharan African cities, revealing several key insights about the urban energy landscape in the region. The analysis demonstrates significant variations in energy consumption patterns, both between cities and within, shaped by factors including economic development, income distribution and other unique structural features.

Several findings emerge from this analysis:

First, there is a clear correlation between economic development and energy consumption patterns, though this relationship is complex. While larger cities like Cape Town, Dakar, and Nairobi demonstrate higher per capita energy consumption (averaging 27 GJ per year), they show markedly better efficiency in converting energy into economic output, indicating that economic development is accompanied by improvements in energy efficiency. Nonetheless, the studied cities' energy consumption all fall largely below the global average, highlighting substantial energy access gaps that need addressing to support development aspirations.

Second, the analysis reveals persistent inequalities in energy consumption within cities. Energy use Gini coefficients range from 0.27 to 0.42, with the most pronounced disparities observed in Cape Town and Yaoundé. Notably, these energy inequalities are consistently lower than income inequalities (averaging 41% lower) and emissions inequalities (averaging 20% lower), suggesting that energy access, while unequal, is more equitably distributed than income and emissions.

Third, the sectoral distribution of energy demand varies significantly with city size. Transport dominates energy consumption in larger economies (averaging 58% of total final energy demand), while the residential sector predominates in smaller cities like Kasese and Tsévié (averaging 64%). This pattern reflects different stages of urban development and infrastructure needs across the cities studied.

Fourth, the analysis highlights concerning patterns in residential energy use. While electricity access varies widely (from 24% in Tsévié to 98% in Cape Town), biomass remains a significant energy source, particularly in smaller cities where it accounts for up to 95% of household energy demand. This reliance on biomass, combined with inequitable use and access to modern energy services, perpetuates energy poverty and associated health impacts, particularly among lower-income households. The study also finds that electricity use is among the most unequal across all energy carriers with the Gini coefficient of electricity use generally much higher than energy use inequalities and at times exceeding the Gini coefficient of income.

Fifth, energy-related GHG emissions patterns reveal varying levels of carbon efficiency across cities. While emissions per capita remain generally well below the global average of 4.8 tCO2e, emissions intensities vary dramatically, from 339 tCO2e/million US$ in Nairobi to 3,410 tCO2e/million US$ in Kasese. This variation suggests that pathways to economic development can have vastly different carbon implications. Nonetheless, the analysis equally points out to significant disparities in emissions between cities (ranging from 0.2 tCO2e in Tsévié to 4.7 tCO2e in Cape Town) and within cities (with emissions Gini coefficients ranging from 0.30 to 0.50).

The analysis also underscores critical data gaps, particularly in the productive use sectors, where better information is needed to fully understand how policy decisions can help unlock these key sectors of economic productivity. Despite these limitations, this study provides valuable insights into the complex relationship between urban development, energy use, and emissions in Sub-Saharan African cities, contributing to the broader understanding needed to guide sustainable and equitable urban development in the region.

Building on the insights and findings on the variations in energy use, emissions, and related inequalities across the studied cities in the base year, as discussed in this chapter, Chapter 5 examines how existing urban energy and climate policies, as captured in the STEPS scenario, might affect these patterns and inequalities in the coming decades.

Chapter 5 : Evaluating the Equity Impacts of Existing Urban Energy Policies

Building on the base year picture of sectoral energy demand, household energy use, GHG and income inequalities detailed in Chapter Four, this chapter first examines the potential effectiveness of stated energy policies (STEPS) – articulated in the existing energy strategies and climate action plans of the six cities under study. This upfront focus on STEPS provides essential context for understanding both current policy effectiveness and the alternative pathways explored in Chapter 6. Following this analysis of STEPS as a whole, the chapter then decomposes these impacts to understand how its individual Policies and Measures (PAMs) contribute to the observed outcomes. Using Gini coefficients and other indicators of energy poverty and clean energy access, the analysis highlights gaps that currently hinder more equitable, energy-intensive urban economies.

In so doing, this chapter provides evidence to answer research question 3 of this thesis: "What conceptual and empirical evidence suggests whether existing local strategies, policies, or plans for clean energy transition are effective or not in addressing development priorities in a fair and equitable manner that reduces inequalities?"

5.1. STEPS scenario description

Under the C40 CAP Africa Program, three cities - Dakar, Nairobi, and Cape Town - received technical support to develop ambitious climate action plans targeting carbon neutrality by 2050. In parallel, Yaoundé and Tsevié developed Sustainable Energy Access and Climate Action Plans (SEACAPs) through the CoMSSA initiative, while Kasese formulated its municipal energy strategy in 2017 through the SAMSET project, focusing on energy sustainability. Despite their different origins, these plans share common elements in that they align with or exceed National Determined Contributions (NDC) targets, emphasize GHG emissions reductions, aim to improve energy access, and address climate adaptation needs. Across all six cities, these strategies identify high-impact Policies and Measures (PAMs) targeting key sectors including waste, energy, buildings, industry, and transport, while promoting clean energy access.

The following section describes a harmonized storyline that captures the objectives, governance structure and implementation mechanisms envisaged under this stated energy policies – STEPS – scenario.

5.1.1. STEPS scenario storyline

Premise: As already highlighted, the STEPS scenario, also referred to as the reference or baseline scenario, takes its bearings from the cities' energy strategies and action plans, focusing on emissions reductions across all sectors while enhancing energy access. However, it refrains from prioritizing an equitable outcome.

In the reference scenario, the energy transition pathway is predominantly **focused on achieving emission reductions and improving energy access**. As part of their commitment to sustainability and environmental stewardship, the cities have set targets to reduce greenhouse gas emissions across various sectors.

One of the key elements of this scenario is the **adoption of cleaner energy technologies**. The cities channel investments toward renewable energy options like distributed solar and storage resources, albeit mostly aimed at powering municipal and public assets.

In tandem, **energy efficiency** efforts take a quiet stage, playing a supporting role in the energy transition. Simple swaps to energy-efficient appliances and the adoption of unobtrusive LED lighting technologies contribute to pockets of energy savings that, while modest, hold value.

With a deliberate tempo, **a shift to mass transit and electrification of the transportation sector** become focal points for emission reduction endeavours. The cities use their modest powers to promote the adoption of electric vehicles and investments in public transportation infrastructure in an attempt to curb emissions.

The energy transition pathway softly emphasizes a nudge toward improved energy access, particularly in the corners of underserved communities. In gradual steps, **electricity grid coverage extends its reach** to remote areas, and unobtrusive efforts provide dependable and budget-friendly energy services to all residents. This includes the deployment of decentralized renewable energy solutions like mini-grids, standalone solar systems or solar home systems.

5.1.2. Implementation of STEPS in the UHEM model

The implementation of STEPS in the UHEM framework deliberately concentrates on residential energy use, despite the comprehensive scope of CAPs across multiple sectors. This methodological choice facilitates detailed quantitative analysis of household energy equity impacts, even as we acknowledge that CAP's transformative potential extends beyond residential considerations. Consequently, the implementation and therefore analysis of STEPS in the UHEM model focuses on a selected subset of energy PAMs, which are:

- Clean cooking adoption
- Electricity access expansion
- Energy efficiency improvements
- Distributed generation (e.g. rooftop solar PV)
- Grid decarbonization through utility-scale renewable energy

The analysis seeks to understand how these STEPS might shape future household energy use and emissions patterns through 2040, with particular attention to energy inequalities across different household quintiles. The energy PAMs listed above and further detailed in Table 11 are distinct from income redistributive PAMs, analysed in section 6.3.

STEPS was implemented in the LEAP-based Urban Household Energy Model (UHEM) and calibrated to reflect the PAM objectives outlined in existing CAPs and summarized in Table 11. Specifically, the table specifically shows how the qualitative narratives were translated into quantitative parameters within the UHEM model. While most PAMs specify uniform targets across all households, in cases where quintile-specific variations were not provided, the methodology detailed in section 3.6.2 was applied to model the nuanced implementation across different household quintiles.

Energy PAM	Description	Implementation in the STEPS scenario					
		Dakar	**Cape Town**	**Nairobi**	**Yaoundé**	**Kasese**	**Tsevié**
Energy Efficiency (EFF)	This intervention models the gradual penetration of energy-efficient appliances for lighting, cooling and heating and other entertainment appliances, thereby reducing electricity consumption and associated emissions.	**Lighting**: According to Dakar's CAP, there is an expected penetration of 80% LED usage across all households by 2040. We also assume that the use of backup diesel generators will persist into the future. **Cooling**: Dakar's CAP targets that 40% of the existing cooling appliances will be retrofitted by 2040. The author assumes that new cooling equipment are 20% more efficient than old ones (Mastrucci *et al.*, 2019) **Space Heating**: There is little to no usage of space heating appliances in Dakar due to weather conditions. The CAP therefore has no specific action targeting space heating. **Other appliances**: the CAP also indicates that approximately 70% of all appliances,	**Lighting**: Cape Town's CAP anticipates a complete retrofit of lighting appliances with LED by 2030 across all households. **Cooling**: There is little to no usage of cooling appliances in cape Town due to weather conditions. The CAP therefore has no specific action targeting cooling. **Water Heating:** In the base year, the demand for water heating is predominantly met through electricity. However, the CAP projects that by 2040, 10% of households will transition to more efficient heating methods, such as heat pumps. Efficient water heating appliances are assumed to be 35% more efficient than the conventional appliances (Ye, Koch and Zhang, 2018). **Space Heating**: In terms of space heating, it is projected	**Lighting**: Nairobi's CAP sets ambitious targets to completely phase out CFL and other outdated lighting technologies in favour of LEDs. Additionally, it is assumed that the use of backup diesel generators will continue into the foreseeable future. **Cooling**: Nairobi's CAP targets that 70% of the existing cooling appliances will be retrofitted by 2040. However, this transition will mainly occur in Q5 given that only a negligible amount of cooling happens in this income group in the base year. The author assumes that new cooling equipment are 20% more efficient than old	Yaoundé's CAP is less specific about energy efficiency interventions. Most targets are informed by the author's work with the local municipality during the drafting of their CAP. **Lighting**: It is assumed that the majority of existing CFL and incandescent lighting technologies will be phased out in favour of LEDs. **Cooling**: no CAP target regarding efficient cooling. **Space Heating**: There is little to no usage of space heating appliances in Yaoundé due to weather conditions. The CAP therefore has no specific action targeting space heating.	**Lighting**: we assume that market forces in Kasese drive the complete phaseout of CFLs and incandescent light in favour of LEDs. **Cooling**: about 5% of households are expected to switch to more efficient forms of cooling. The author assumes that new cooling equipment are 20% more efficient than old ones (Mastrucci *et al.*, 2019) **Space Heating**: There is little to no usage of space heating appliances in Kasese due to weather conditions. The CAP therefore has no specific action targeting space heating.	Similar to Yaoundé, Tsévié's CAP has vague targets on energy efficiency. Those mentioned below are informed by the author's work the local municipality in the drafting of their CAP. **Lighting**: we assume that market forces in Kasese drive the complete phaseout of CFLs and incandescent light in favour of LEDs. **Cooling**: no CAP target regarding efficient cooling. **Space Heating**: There is little to no usage of space heating appliances in Tsévié due to weather conditions. The CAP therefore has no specific action targeting space heating.

		including refrigeration units, will be upgraded to more efficient models by 2040. The author estimates that new refrigeration devices will be 15% more efficient than their predecessors (McNeil and Letschert, 2010), while other general appliances can be up to 25% more efficient into the future (Dioha MO, 2017).	that only about 15% of households will transition to more efficient heating appliances. The author estimatse that this transition will occur predominantly among the higher income quintiles (Q4 and Q5). Under current trends, these more efficient heating appliances are anticipated to be over 35% more efficient than conventional ones. **Other appliances**: the CAP also indicates that approximately 70% of all appliances, including refrigeration units, will be upgraded to more efficient models by 2040. The author estimates that new refrigeration devices will be 15% more efficient than their predecessors (McNeil and Letschert, 2010), while other general appliances can be up to 25% more efficient into the future (Dioha MO, 2017).	ones (Mastrucci *et al.*, 2019) **Space Heating**: There is little to no usage of space heating appliances in Nairobi due to weather conditions. The CAP therefore has no specific action targeting space heating. **Other appliances**: On average, 40% of all appliances, including refrigeration units, will be upgraded to more efficient models by 2040. The author estimates that new refrigeration devices will be 15% more efficient than their predecessors (McNeil and Letschert, 2010), while other general appliances can	**Other appliances**: we assume that about 50% of households retrofit existing inefficient appliances with more efficient ones. The author estimates that new refrigeration devices will be 15% more efficient than their predecessors (McNeil and Letschert, 2010), while other general appliances can be up to 25% more efficient into the future (Dioha MO, 2017).	**Other appliances**: based off Kasese's CAP, about 35% of household adopt more efficient appliances (including refrigeration) by 2040. The author estimates that new refrigeration devices will be 15% more efficient than their predecessors (McNeil and Letschert, 2010), while other general appliances can be up to 25% more efficient into the future (Dioha MO, 2017).	**Other appliances**: It is estimated that about 40% of households retrofit existing inefficient appliances with more efficient ones. The author estimates that new refrigeration devices will be 15% more efficient than their predecessors (McNeil and Letschert, 2010), while other general appliances can be up to 25% more efficient into the future (Dioha MO, 2017).

				be up to 25% more efficient into the future (Dioha MO, 2017).			
Distributed Generation (DGN)	Distributed Generation (DG), mostly rooftop solar PV, refers to a variety of technologies that generate electricity at or near where it will be used. While this intervention does not change the overall quantity of electricity use by specific households, we assume that these installations will typically meet 40% of the installer's electricity consumption.	The CAP anticipates that 30% of all residential buildings will adopt distributed forms of energy by the year 2040, reducing their electricity carbon footprint accordingly.	Based off the Cape Town's notable uptake of DG in recent years, the author estimates a more ambitious DG rollout relative to the CAP target, reaching 75% penetration in Q5 by 2040.	The CAP anticipates that 20% of all residential buildings will adopt distributed forms of energy by the year 2040, reducing their electricity carbon footprint accordingly.	There are no targets for DG uptake in the city's CAP. The author however estimates that 30% of affluent households in Q4 and Q5 will have DG installation by 2040	There are no targets for DG uptake in the city's CAP. The author however estimates that 30% of affluent households in Q4 and Q5 will have DG installation by 2040	There are no targets for DG uptake in the city's CAP. The author however estimates that 30% of affluent households in Q4 and Q5 will have DG installation by 2040

Clean Cooking (COOK)	The clean cooking intervention includes the introduction of cleaner, more efficient cooking technologies to replace traditional methods in households, as well as fuel switching. As water heating is narrowly linked to cooking (except for Cape Town), the author assumes that both end services will experience similar transformations.	According to Dakar's CAP, there is an expectation that half of existing charcoal stoves will be replaced with LPG stoves. Simultaneously, households that are already utilizing LPG stoves are expected to gradually transition towards electric stoves.	The city's CAP anticipates a complete phase out of other forms of cooking (LPG and paraffin) in favour of electricity	According to Nairobi's CAP, there's an expectation that LPG alternatives will replace half of all existing cooking fuels.	All existing traditional cooking technologies (wood and charcoal) are completely replaced with more efficient ones by 2030.	Kasese's CAP targets the phase out of half of existing charcoal and wood stoves by 2030 due to more efficient and affordable LPG alternatives	Half of all existing cooking technologies are replaced with more efficient ones by 2030. No fuel switching.
Electricity Access (ACCESS)	This intervention models the expanded access to electricity for households to reach universal electrification by 2040. The incremental access to electricity is assumed to be facilitated through decentralized	The CAP establishes a goal of achieving complete household electrification by 2030. Based on these projected electricity access rates, we utilize the formulas described in the methodology chapter (section 3.6.2) to calculate the anticipated ownership levels of new appliances and technologies, as well as the services they provide.					

	renewable energy sources.						
Clean electricity supply (CLEAN ELEC)	This initiative focuses on increasing the proportion of renewable energy sources within the national energy mix, aligning with the targets specified in the Nationally Determined Contributions (NDCs). In LEAP, this will translate to reduced electricity emission intensities.	The CAP projects that renewables will make up 46% of the national energy mix by 2040.	The city's decarbonization goal aims to reduce dependence on Eskom, the national utility, by 30% by integrating alternative renewable energy sources from a mix of Independent Power Producers (IPPs) and other entities.	The CAP anticipates that the share of RE on the supply side will climb to 100% from 86% in the base year.	The CAP does not specify decarbonization targets. Consequently, we have adopted the targets set in the NDC which has a conditional target of 32% for the power sector	The CAP does not specify decarbonization targets. Consequently, we have adopted the targets set in the NDC which has a conditional target of 36% for the power sector	The CAP does not specify decarbonization targets. Consequently, we have adopted the targets set in the NDC which has a conditional target of 30% for the power sector

Table 11. PAM description

5.2. Impact analysis of STEPS scenario and individual PAMs

This section evaluates the impact of STEPS on household energy use and emissions inequalities across the study cities. The analysis proceeds in two stages: first, it examines the combined effects of all PAMs within STEPS, offering a broad assessment of how current policy trajectories shape energy equity. It then shifts to a detailed decomposition of individual PAMs, shedding light on their respective contributions to the observed STEPS outcomes.

Given the extensive array of results generated, we streamline our discussion to a select subset of key findings here, with an expanded compilation available in an online SI file. In reporting key results in this chapter, the thesis focuses on the effect of STEPS on key indicators of sustainability as well as its influence inequality trajectories for each study city. Moreover, specific interventions or PAMs are selectively discussed when they offer valuable insights or serve to emphasize critical aspects of the thesis. Tables and figures in the following section report results from the modelling undertaken, so no source is stated.

5.2.1. Impact analysis of STEPS

Table 12 summarizes key indicators of energy sustainability for the six study cities, encompassing social, economic, and environmental dimensions. The detailed analysis of these indicators is presented in the following sections.

Indicator	Units	Dakar	Cape Town	Nairobi	Yaoundé IV	Kasese	Tsévié
Social Dimension							
Gini coeff of household energy use – **Base year**		0.27	0.42	0.30	0.42	0.27	0.31
Gini coeff of household energy use – **STEPS (2040)**		0.14	0.26	0.20	0.20	0.08	0.18
Share of population with electricity – **Base year**	%	94%	98%	97%	95%	48%	24%
Share of population with electricity – **STEPS (2040)**	%	100%	100%	100%	100%	100%	100%
Share of biomass on household total energy demand – **Base year**	%	45%	0%	8%	18%	97%	95%
Share of biomass on household total energy demand – **STEPS (2040)**	%	35%	0%	8%	10%	74%	71%
Share of electricity on household total energy demand – **Base year**	%	26.0%	91.0%	22.0%	23.0%	2.0%	4.0%
Share of electricity on household total energy demand – **STEPS (2040)**	%	46.9%	98.9%	41.7%	32.4%	12.8%	11.0%
Top 20% (Q5) share of total final household energy use – **Base year**	%	29%	50%	32%	40%	25%	31%
Top 20% (Q5) share of total final household energy use – **STEPS (2040)**	%	20%	25%	32%	33%	24%	29%
Economic Dimension							

Household energy use ratio between Q5 and Q1 – **Base year**		1.94	4.39	2.06	4.06	1.88	2.20
Household energy use ratio between Q5 and Q1 – **STEPS (2040)**		0.92	3.09	1.68	2.49	2.53	2.83
Average household electricity consumption – **Base year**	kWh	860	3059	351	939	203	177
Average household electricity consumption – **STEPS (2040)**	kWh	2538	3665	496	1300	1238	527
Environmental Dimension							
Gini coeff of household GHG emissions – **Base year**		0.41	0.43	0.41	0.47	0.30	0.50
Gini coeff of household GHG emissions – **STEPS (2040)**		0.20	0.23	0.34	0.24	0.19	0.29
Top 20% (Q5) share of total household GHG emissions – **Base year**	%	41%	51%	40%	44%	29%	47%
Top 20% (Q5) share of total household GHG emissions – **STEPS (2040)**	%	30%	33%	34%	36%	28%	37%
Household GHG emissions ratio between Q5 and Q1 – **Base year**		9.54	6.40	5.74	9.79	3.19	12.07
Household GHG emissions ratio between Q5 and Q1 – **STEPS (2040)**		1.46	2.60	3.19	1.80	2.18	2.31

Table 12. Indicators of energy sustainability for the study cities under the STEPS scenarios by 2040 and base year.

Analysis of the STEPS scenario reveals varied outcomes in addressing household energy use and emissions inequalities across the study cities. The outcomes are shown for STEPS and for the base year in separate rows. The modelling results demonstrate that despite these policies not being explicitly designed with equity considerations, they yield substantial impacts on energy distribution patterns. Specifically, implementation of stated policies could achieve reductions in the Gini coefficient of household energy use ranging from 33% in Nairobi to 48% in Dakar by 2040. However, it is noteworthy that in Tsévié, STEPS appear to exacerbate existing disparities, with the model projecting an increase in the energy use Gini coefficient by 17 percentage points from the base year. Similar patterns emerge in emissions inequalities, where STEPS demonstrates considerable effectiveness in reducing Gini coefficients, achieving reductions ranging from 17% in Nairobi to a remarkable 46% in Cape Town, as illustrated in Figure 40.

The indicators of sustainability, reported in Table 12, also indicate notable improvements across multiple indicators compared to base year figures. Particularly noteworthy is the modelled household electricity consumption patterns. The model suggests nearly threefold increases in average household electricity consumption in Dakar and Tsévié, while Kasese shows an even more dramatic improvement with a projected sixfold increase - Figure 41. Similar positive trends are observed in total final energy use by household quintiles, with Cape Town, Nairobi, and Yaoundé all showing two to threefold increases.

Important gains are also made in terms of clean energy access with significant shifts projected in household energy mix compositions by 2040. Results indicate substantial reductions in biomass dependency under STEPS, with its share in the household energy mix decreasing by approximately 10% in Dakar and Yaoundé, and more than 20% in Kasese and Tsévié. Concurrent with this reduction, the model projects an average 8% increase in electricity's share across most study cities. It is important to note however that biomass will remain a predominant energy source for households in Kasese and Tsévié under the STEPS scenario.

If the base year energy-to-household income ratio (GJ/$) for each quintile in each city were to remain constant throughout the model period, the successful implementation of the STEPS scenario could hypothetically reduce income inequalities by 10-40% across the study cities. However, these findings may need further investigations as the calculations may oversimplify the complex relationship between energy and income – a relationship that is not yet fully understood, particularly for the African cities under examination.

While the STEPS scenario demonstrates effectiveness in addressing various metrics of energy use and emissions inequalities, particularly through improvements in overall Gini coefficients, pronounced inequalities persists. This is particularly evident in electricity access and utilization patterns, where substantial disparities persist as will be demonstrated in the subsequent sections.

The subsequent section delves into a differentiated analysis of STEPS to understand how individual PAMs contribute to the observed outcomes in energy use and emissions patterns across different household quintiles.

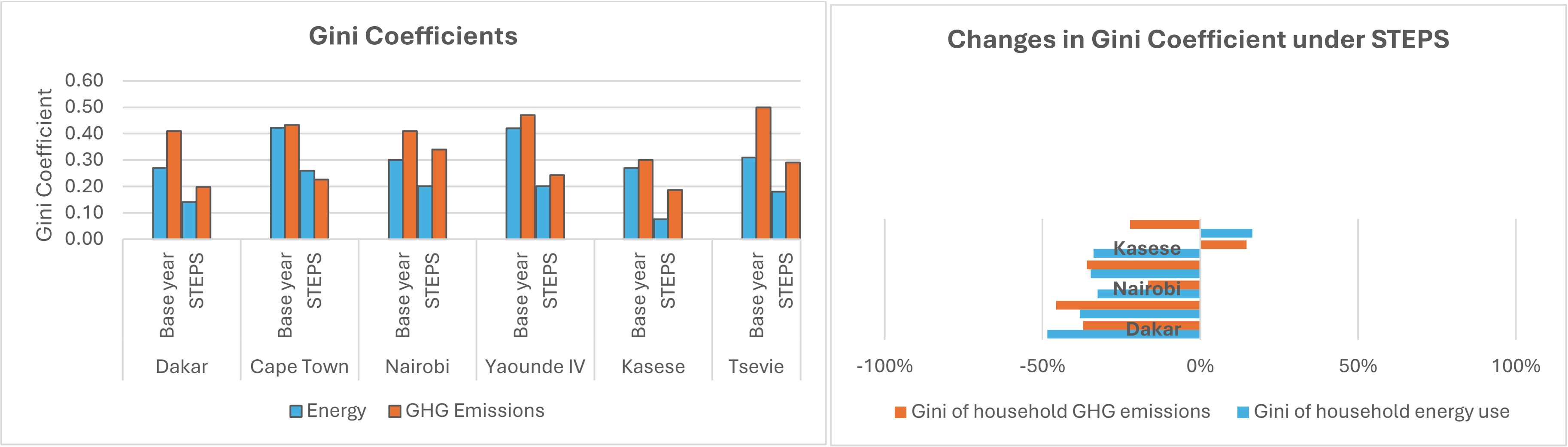


Figure 40. Gini coefficients under STEPS in 2040 (left panel) and changes in Gini coefficients under STEPS relative to the BAU scenario (right panel).
Note: Negative values signal reduced inequalities while positive values indicate a widened inequality gap. All Gini coefficients are calculated using useful energy.

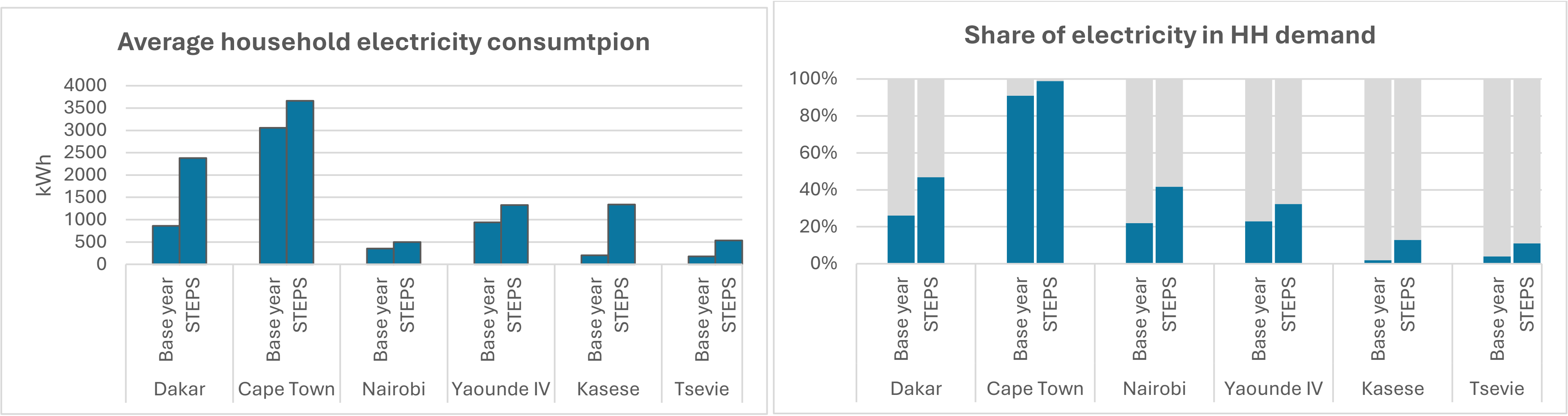


Figure 41. Average household final electricity consumption under STEPS in 2040 (left panel) and shares of electricity in final household energy (right panel)

5.2.2. Decomposing STEPS' impact: Analysis of individual PAMs

Having established the overall impact of STEPS on energy inequalities, we now examine how individual PAMs contribute to these outcomes. This decomposition analysis reveals which specific interventions drive the greatest changes in energy inequality metrics, providing crucial insights for policy design.

Figure 42 shows a panel of graphs that summarize the disaggregated impacts of all individually modelled PAM across all six study cities by 2040. It is evident that the impact of these PAMs on the Gini coefficient for household energy use and GHG emissions varies significantly across the study cities, even when policy targets may be identical. Notably, interventions related to clean cooking and electricity access are the most effective in reducing household energy use inequalities. Meanwhile, clean electricity supply is generally more effective in reducing household GHG emissions inequalities.

a. **Impact of Clean Cooking 'COOK'** - Figure 42a: Given the varied nature of clean cooking targets within existing policies, the implementation of COOK in the UHEM model results in diverse outcomes. As cooking constitutes a significant portion of household energy demand, the resulting household energy mix changes based on the ambition levels defined in the COOK policy. The most substantial shifts in energy mix relative to the base year are observed in Dakar, where the share of electricity in household quintiles Q3-Q5 more than doubles, while concurrently, the share of LPG consumption in Q1-Q2 also follows a similar trend – see Figure 44. Conversely, Cape Town, Nairobi, and Yaoundé exhibit the least noticeable shifts in household energy mix, reflecting the more modest ambitions of their COOK targets.

   As a result, in Dakar, the COOK intervention significantly reduces household energy use inequalities by as much as 32% relative to the base year, while in Cape Town, Nairobi and Yaoundé, the impact is less significant. In Kasese and Tsévié, however, the shift towards cleaner or more efficient cooking technologies unexpectedly increases base year inequalities. For instance, in Kasese, household energy use inequalities surge by as much as 76%. As discussed in the individual city case studies in the next section, these outcomes primarily arise from substantial efficiency gains in the lower income quintiles, as they switch to cleaner and more efficient cooking alternatives, thereby widening the inequality gap.

   However, the analysis also shows that the COOK intervention often benefits the upper income quintiles the most, as these households are usually the first to move up to higher tiers in the MTF framework.

b. **Impact of Energy Efficiency 'EFF'** - Figure 42b**:** The influence of energy efficiency measures is more consistent across all the study cities, showcasing varied levels of reductions in household consumption inequalities, with the most notable impact observed in Yaoundé and Cape Town. Specifically, in these two cities, the EFF intervention is particularly effective in the upper income quintiles, where it significantly reduces the share of electricity in these households' energy mix by 20-37%, thus narrowing the energy use gap between the different household quintiles.

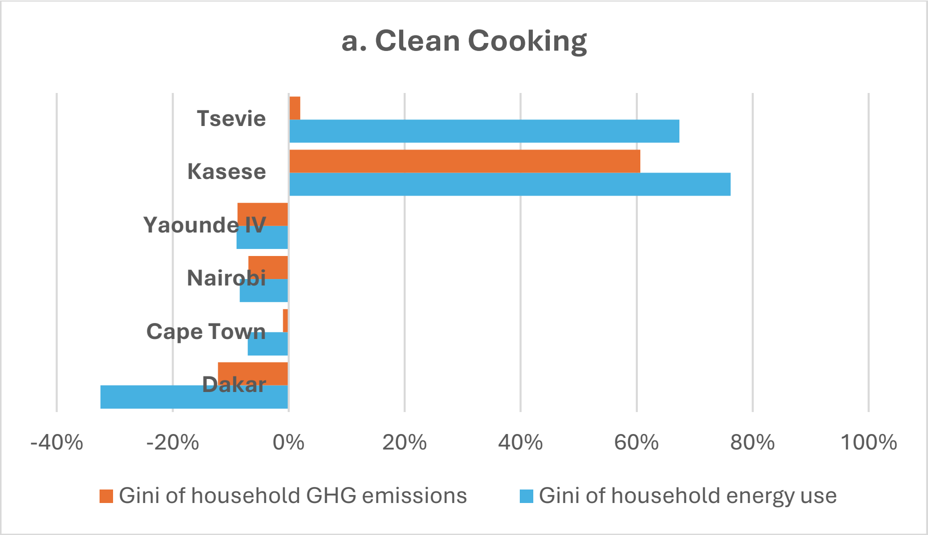
c. **Impact of Distributed Generation 'DGN' -** Figure 42c**:** The deployment of distributed generation, intuitively reduces GHG emissions across income quintiles in each city. As more affluent households transition their electricity consumption to these cleaner alternatives, their net GHG emissions decrease proportionately, producing a levelling effect that reduces the disparities in GHG emissions across the income spectrum.
   However, although not shown in the modelling, the benefits of DG are predominantly accrued by higher income quintiles, who are more likely to afford and access these technologies. This skew could potentially exacerbate energy access inequalities, as lower-income households may not equally share the advantages of these distributed energy sources. The nuances of these equity implications are discussed in more detail in Chapter 7.

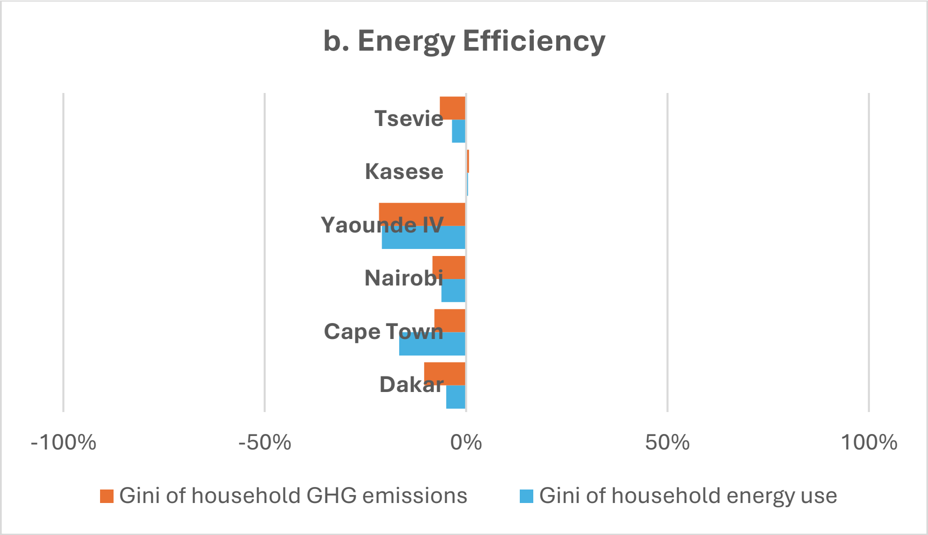
d. **Impact of Electricity Access 'ACCESS' -** Figure 42d**:** Next to clean cooking, electricity access PAM has among the most significant impacts on inequalities and other sustainability metrics. For example, in Kasese and Tsévié, the share of electricity and LPG in the household energy mix grows nearly sixfold across all household quintiles, representing the most significant shifts among all the study cities. In Kasese, this substantial expansion in clean energy access significantly levels existing household energy use disparities, effectively neutralizing base year inequalities in household energy use, while in Cape Town, this intervention has little effect due to the high levels of access in the base year.

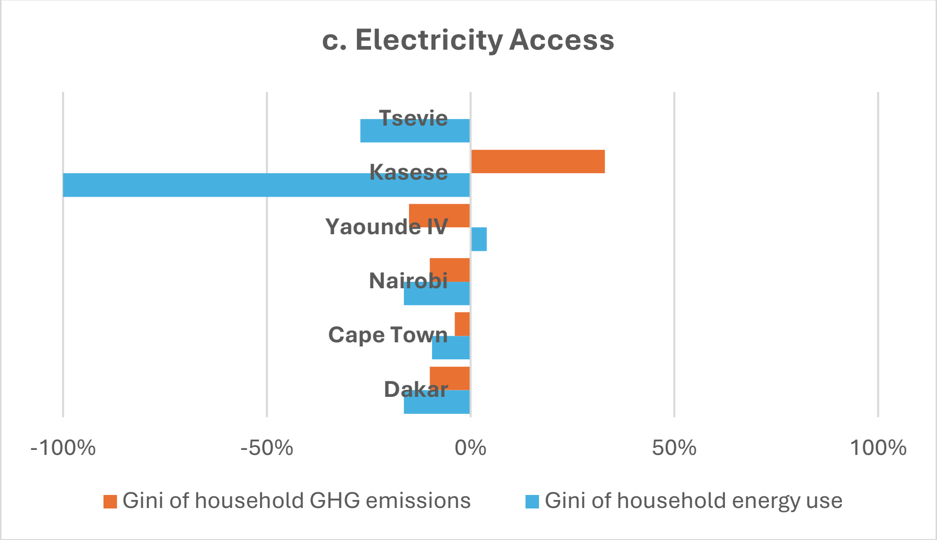
   Yaoundé presents a notable exception. Despite significant positive shifts in clean energy access under the ACCESS intervention, the PAM inadvertently widens inequality gaps due to efficiency gains in the lower quintiles from reduced biomass use as explained in Yaoundé's case study in the next section.

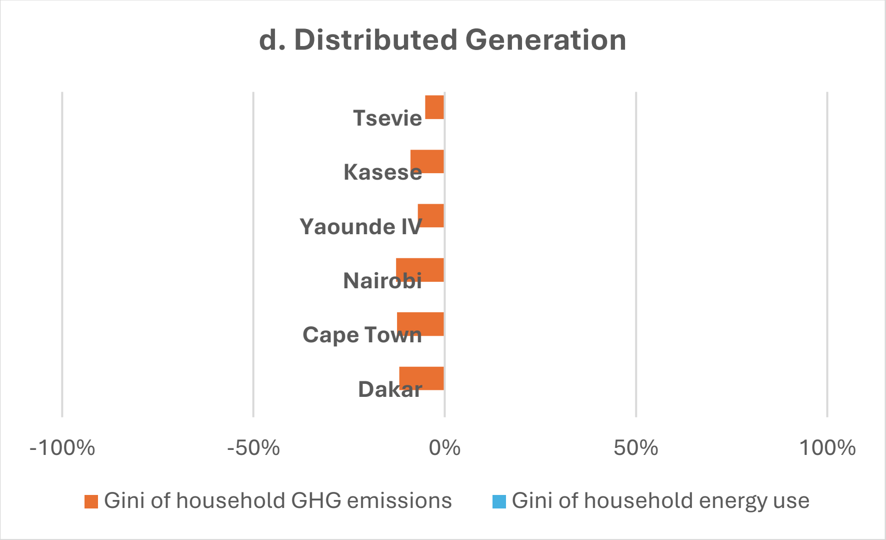
e. **Impact of Clean Electricity 'CLEAN ELEC'** - Figure 42e: Although the direct implementation of clean electricity supply strategies often falls outside the jurisdiction of the studied local municipalities – with Cape Town being an exception – decarbonizing the electricity grid is the most universally effective intervention for reducing household emissions inequalities across the cities examined. The extent of impact does not correlate with city size but rather depends on a combination of factors, including the base year inequalities in emissions from electricity consumption and the ambition of decarbonization efforts encapsulated in national or local policies. For instance, initiatives to clean the grid supply have demonstrated the most significant effects in Kasese and Dakar, where the NDCs or CAPs set particularly high targets for decarbonization.

   While only emissions inequalities were modelled, the impact of decarbonizing the grid also extends to a more equitable access to clean energy resources where the benefits such as cheaper electricity tariffs, are shared among all societal segments.


a. Clean Cooking
Tsevie
Kasese
Yaounde IV
Nairobi
Cape Town
Dakar
-40%
-20%
0%
20%
40%
60%
80%
100%
Gini of household GHG emissions
Gini of household energy use


b. Energy Efficiency
Tsevie
Kasese
Yaounde IV
Nairobi
Cape Town
Dakar
-100%
-50%
0%
50%
100%
Gini of household GHG emissions
Gini of household energy use


c. Electricity Access
Tsevie
Kasese
Yaounde IV
Nairobi
Cape Town
Dakar
-100%
-50%
0%
50%
100%
Gini of household GHG emissions
Gini of household energy use


d. Distributed Generation
Tsevie
Kasese
Yaounde IV
Nairobi
Cape Town
Dakar
-100%
-50%
0%
50%
100%
Gini of household GHG emissions
Gini of household energy use

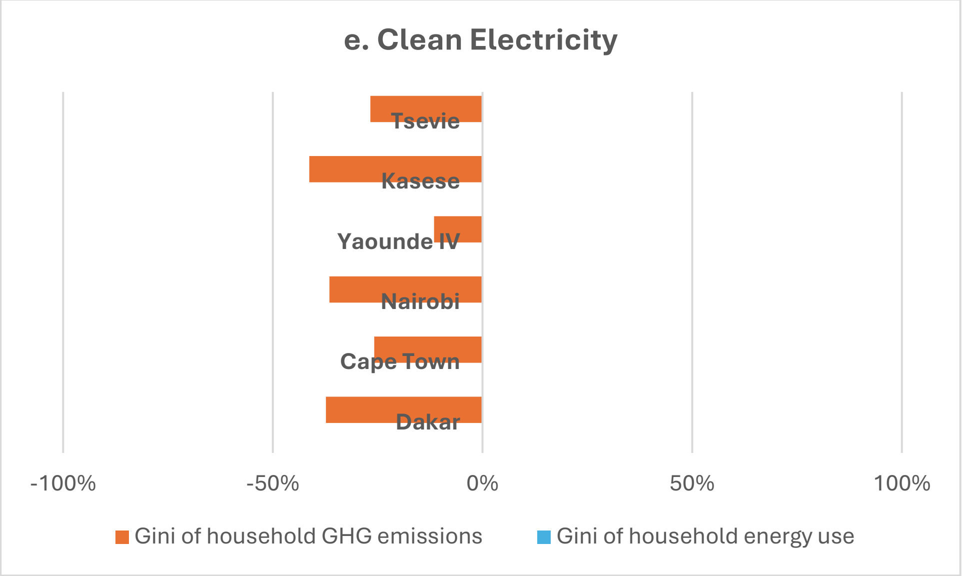


Figure 42. A cross-comparative analysis of the impact of all modelled PAMs in the STEPS scenario.
Note: The graphs indicate the change in the Gini coefficients of household energy use (blue) and GHG emissions (orange) relative to the BAU scenario under STEPS in 2040. Negative values signal reduced inequalities while positive values indicate a widened inequality gap. All Gini coefficients are calculated using useful energy.

5.3. Variations in STEPS outcomes across studied cities

Having examined the aggregate outcomes of STEPS and its constituent PAMs, this section presents detailed city-level analyses to understand how STEPS outcomes are influenced by varying local contexts. Each city's unique characteristics - including base year energy profiles, economic structures, and existing inequalities - shape how STEPS impacts energy and emissions distributions. The following subsections examine each city in turn, analysing how specific local conditions interact with STEPS to produce distinct equity outcomes.

5.3.1. Dakar, Senegal

Figure 43 shows the effect of STEPS on the quintile variations in household energy in Dakar. STEPS demonstrates a significant levelling effect on final energy consumption across household quintiles, with the lower income quintiles (Q1 and Q2) experiencing a near doubling of their final energy use by 2040. Notably, average household electricity consumption rises threefold, from 860 kWh per household in 2016 to over 2500 kWh in 2040 – see Table 12 on detailed impact of STEPS on selected indicators. Despite these gains, existing disparities in the use of specific fuels, such as electricity, persist, as will be shown below.

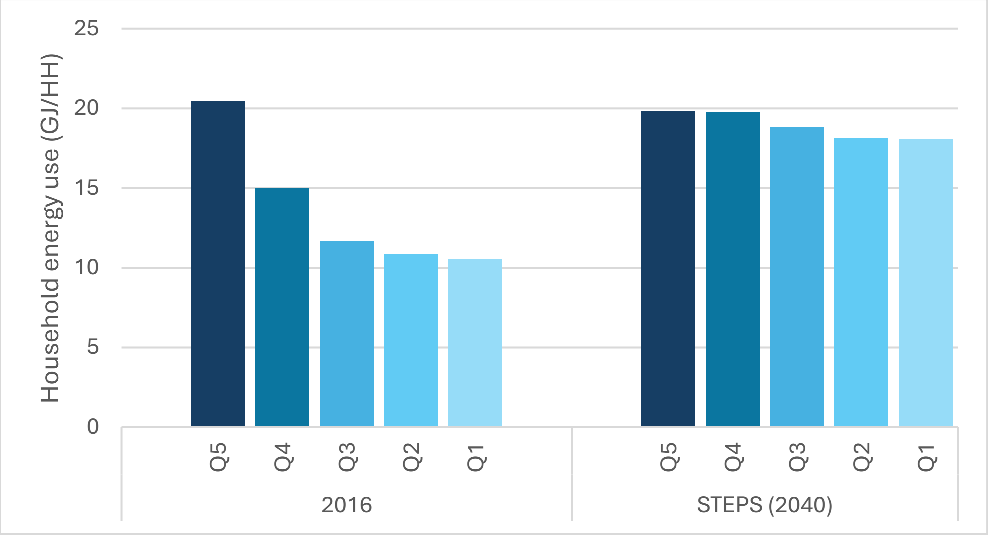


Figure 43. Annual household final energy use (GJ/household) by income quintile under selected policy interventions, Dakar.

Figure 44 and Figure 45 present the projected impact of a STEPS on the Gini coefficients of household energy consumption and GHG emissions in Dakar by 2040.

Clean Cooking ('COOK') is notably the most effective in addressing household energy consumption inequality in Dakar, achieving a substantial 32% reduction in the Gini coefficient of household energy use. This is attributed to the policy's levelling effect on LPG consumption across all income quintiles, particularly as lower-income quintiles (Q1, Q2, and Q3) substantially increase their LPG usage for cooking – see Figure 44b. At the same time, there is equally a sharp drop in biomass (particularly charcoal) consumption in the upper quintiles, as these households switch to more efficient electricity alternatives. This shift indicates that households from Q3 to Q5 have effectively moved out of cooking poverty, reaching tier 3 of the Multi-Tier Framework (MTF) for cooking.

Electricity Access, 'ACCESS' has the second biggest impact on narrowing the energy use gap, followed by energy efficiency 'EFF', each enhancing the Gini coefficient of energy use by ~16% and 5% respectively. The democratized access to electricity in the ACCESS scenario trickles down to an increased adoption of electrical appliances which have been previously inaccessible, therefore increasing the relative share of electricity usage across all income quintiles relative to the base year. The EFF intervention on the other hand mostly reduces the affluent household's electricity consumption across appliances and refrigeration equipment.

In terms of emissions, grid decarbonisation through clean electricity supply 'CLEAN ELEC' has the highest impact on the household emissions inequalities, reducing the Gini coefficient by 37% relative to the BAU. This is primarily because electricity represents the most disproportionately utilized fuel, therefore offering the greatest potential for rectifying GHG emissions disparities. Additionally, Dakar ranks second among the cities studied in terms of electricity emissions intensity, further emphasizing the significant opportunity for intervention. COOK, EFF, ACCESS, and DGN each have relatively modest contributions to reducing GHG emissions inequalities.

The STEPS scenario (all PAMs combined) remarkably reduces household energy use inequalities in Dakar by 2040 by 45% as measured by the Gini coefficient. This is driven by the aggregate impact of clean cooking, energy efficiency and electricity access in redistributing the consumption of various energy fuels, particularly LPG, among all income quintiles. STEPS naturally also has the highest cumulative impact on household emissions distributions, improving the Gini coefficient of over 37% relative to the 2016 levels.

However, it is important to note that despite these overall improvements in energy use and emissions, significant disparities persist in the distribution of electricity and biomass - see Figure 44b. For instance, in 2040, the wealthiest quintile (Q5) still accounts for ~45% of the city’s total household electricity consumption, down from 60% in the base year but still far from achieving an equitable use of this crucial resource.

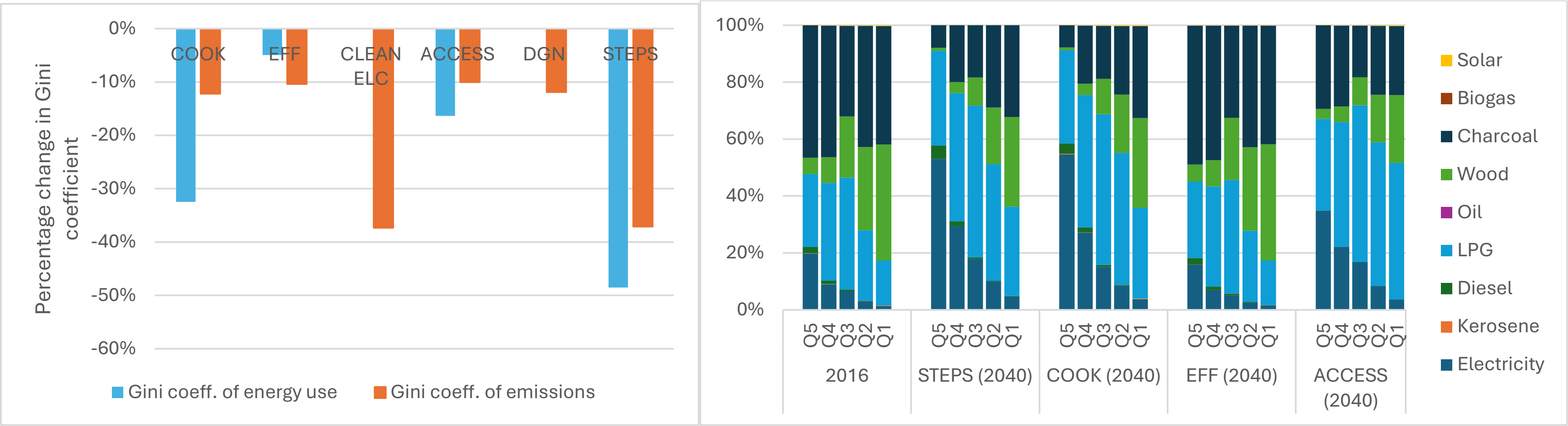


Figure 44. Effect of STEPS on Gini coefficients in 2040 (left panel) and household final energy share by energy carrier by income quintile (right panel), Dakar. All Gini coefficients are calculated using useful energy.

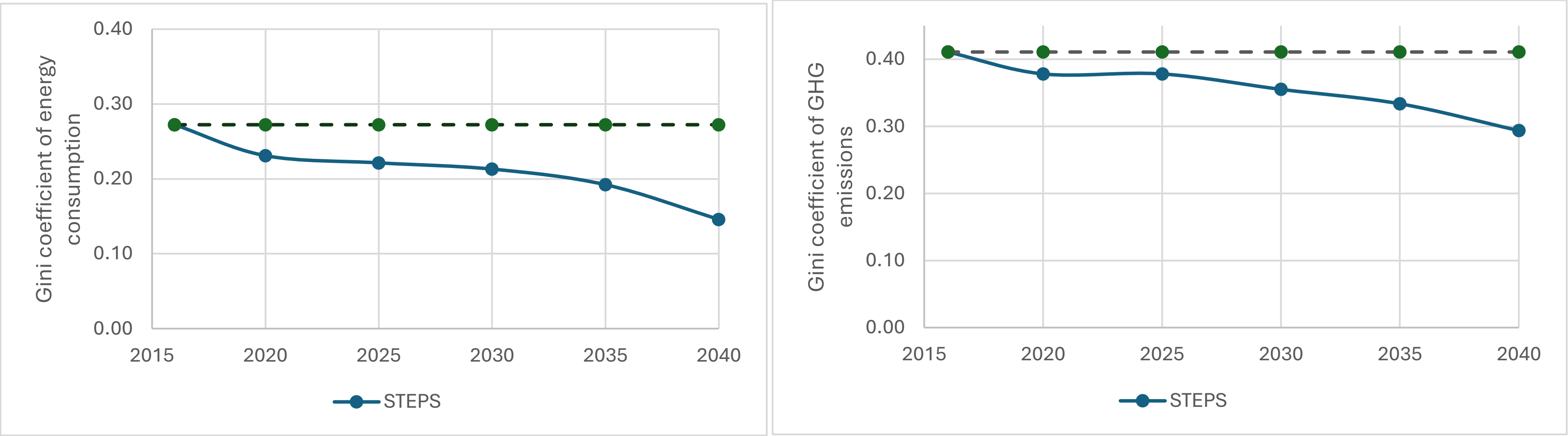


Figure 45. Gini projections of household energy use (left panel) and household GHG emissions (right panel), under the STEPS, Dakar. All Gini coefficients are calculated using useful energy.

5.3.2. Cape Town, South Africa

Figure 46 illustrates the effect of STEPS on household energy consumption variations across different income quintiles in Cape Town. In this scenario, total final energy use increases significantly across all income quintiles, ranging from one and a half to twofold by 2040. This also translates to an increase in average household electricity consumption, which grows from 3,059 kWh per household in the base year (2016) to over 3,600 kWh by 2040, the lowest increase among all study cities.

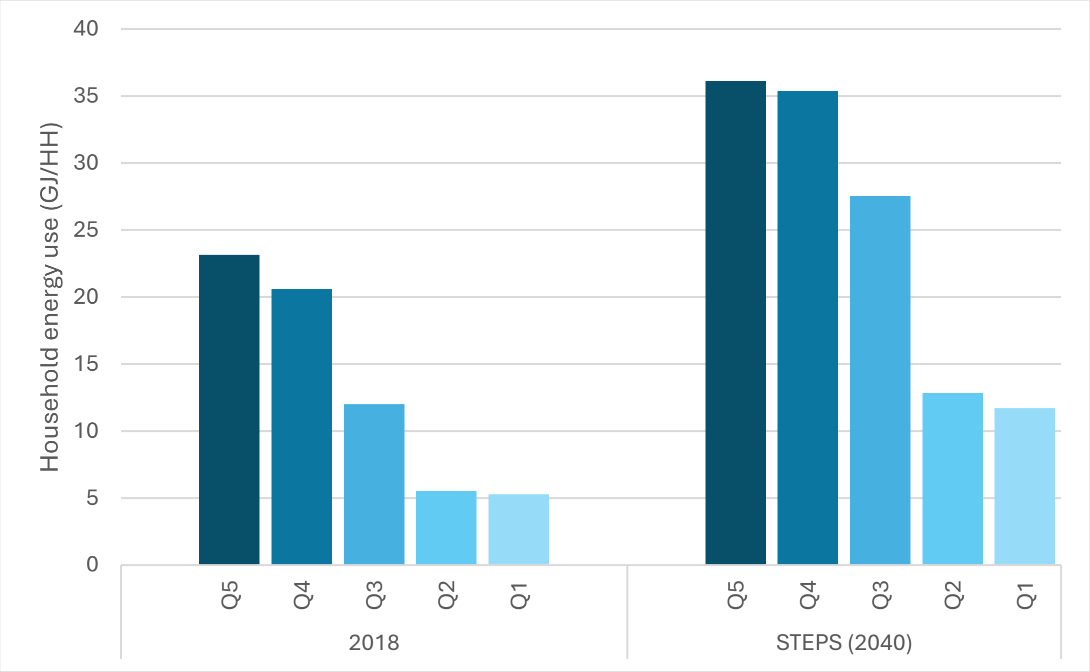


Figure 46. Annual household final energy use (GJ/household) by income quintile under selected policy interventions, Cape Town.

Figure 47a shows that the COOK has minimal influence on the trajectories of the Gini coefficient, unlike with Dakar. This is due to the already high penetration of electricity for cooking purposes among electrified households even within the lower income quintiles (Q1 and Q2), where between 85% and 92% of such households already employ electricity for this end-use in the base year. Consequently, the shift towards clean cooking, while reducing the use of kerosene (Figure 47b) does not constitute a notable change in their energy consumption patterns.

While the COOK intervention aligns with the city's strategy, it is important to note that the latest census data from South Africa, reveals a dramatic decrease in the share of households using kerosene nationally – from 22% in 2011 to below 3% in 2022 (Stats SA, 2023). Given this trend, it is highly probable that all household quintiles in Cape Town will achieve tier 6 of the MTF for cooking by the end of the decade.

On the other hand, EFF has a very modest impact of on both household energy use and GHG emissions inequalities, respectively achieving 7% and 8% reductions in the Gini coefficients. While ACCESS yields little returns on reducing energy disparities, due to Cape Town's high electricity access and the widespread electrification of various end-uses in the base year, it also has a very modest contribution to the Gini coefficient of GHG emissions, improving it by 4%

relative to the 2018 levels. Similar to COOK, both interventions reduce by more than half the share of kerosene usage in Q1 and Q2 - Figure 47b.

As with Dakar, CLEAN ELEC has by far the highest impact on GHG emissions inequalities, reducing household GHG emissions from electricity consumption by more than half relative to the base year and consequently improving the Gini coefficient of household GHG emissions by 26%. Again, this impact is mostly on the account of Cape Town's carbon intensive electricity, and the existing inequality in electricity usage. Distributed Generation also has a modest impact, reducing GHG emissions inequalities by about 12%.

The aggregate effect of the stated policy interventions in the STEPS scenario decreases the household energy inequality Gini coefficient by 7% by 2040 and the GHG emissions Gini coefficient by 45%. A significant portion of the residual emissions, contributing to the unequal distribution of energy use and therefore emissions, comes from electricity consumption. This highlights the necessity for more assertive actions within the electricity sector to address inequalities more substantially.

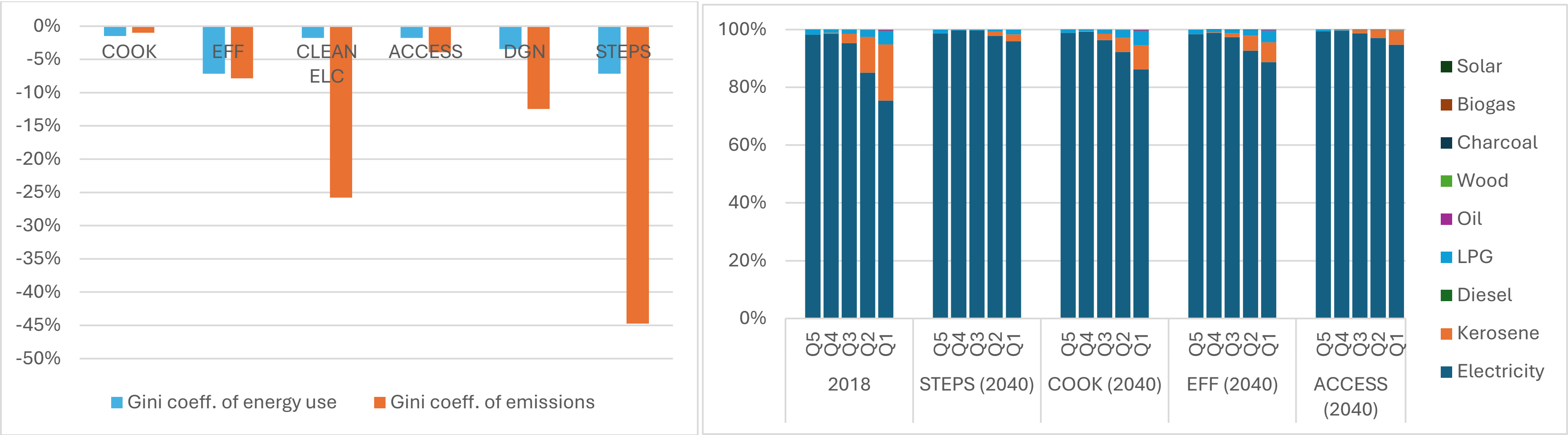


Figure 47. Effect of STEPS on Gini coefficients in 2040 (left panel) and household final energy share by energy carrier by income quintile (right panel), Cape Town
All Gini coefficients are calculated using useful energy.

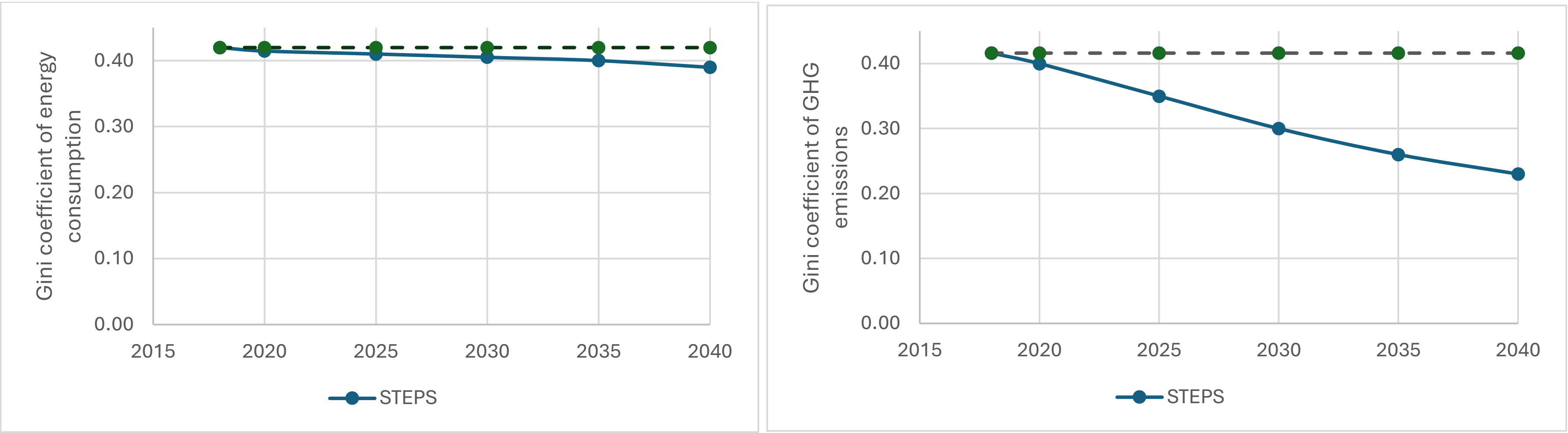


Figure 48. Gini projections of household energy use (left panel) and household GHG emissions (right panel), under the combined set of stated policies, Cape Town.
All Gini coefficients are calculated using useful energy.

5.3.3. Nairobi, Kenya

Figure 49 show the effect STEPS on the quintile variations in household energy in Nairobi. Much like in Cape Town, almost every household quintile in Nairobi experiences a doubling in their total final energy use by 2040 under the STEPS intervention. This significant increase in energy use also translates to a 40% rise in average household electricity consumption compared to the base year. As such, the share of electricity in household energy use increases from 22% in 2016 to 31% in 2040 – see Table 12.

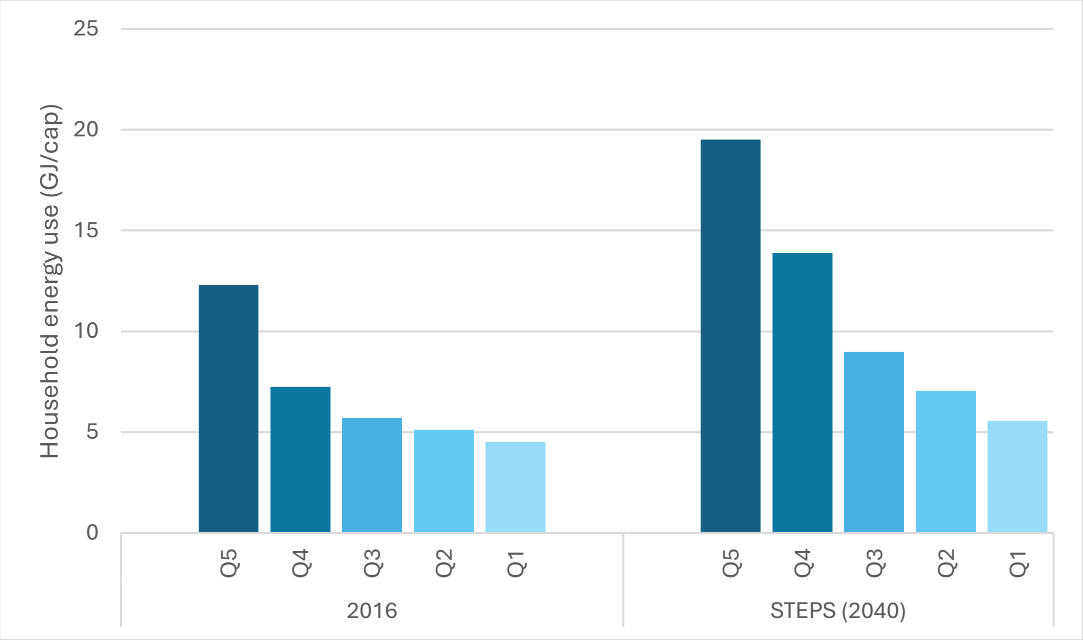


Figure 49. Annual household final energy use (GJ/household) by income quintile under selected policy interventions, Nairobi.

Figure 50 and Figure 51 show the modelled impact STEPS on future trajectories of household energy use and emissions inequalities in Nairobi. The implementation of ACCESS in Nairobi based of the city's CAP could lead to reduce household energy use inequalities by 16% relative to the BAU. While this intervention significantly boosts electricity consumption in the lower income quintiles (Q1 and Q2) by over 40%, however, it simultaneously reduces the use of biomass and kerosene in these quintiles by more than half (see Figure 50b). A similar pattern is observed with the COOK intervention, which reduces total biomass use by nearly 50%, with the biggest energy savings in the less affluent households. EFF and COOK PAMS on the other hand have more modest impacts on the inequalities, reducing the Gini coefficient of energy use by 6 and 8% respectively.

In terms of emissions, the CLEAN ELEC intervention yields the most substantial improvement, reducing the Gini coefficient for emissions by 37%, particularly impacting the power sector. Both DGN and ACCESS achieve more modest reductions in total emissions disparities.

Overall, STEPS scenario sees a reduction in household energy use inequalities of 33% by 2040 relative to the base year. On the emissions, Nairobi's stated policies in the STEPS scenario could significantly reduce the Gini coefficient for GHG emissions distributions by more than 56%. However, a notable shortfall of the STEPS is the persistent disparity in electricity use. Despite increased overall access to and use of clean fuels, the combined share of electricity use by the lowest income quintiles (Q1 and Q2) in 2040 remains almost unchanged.

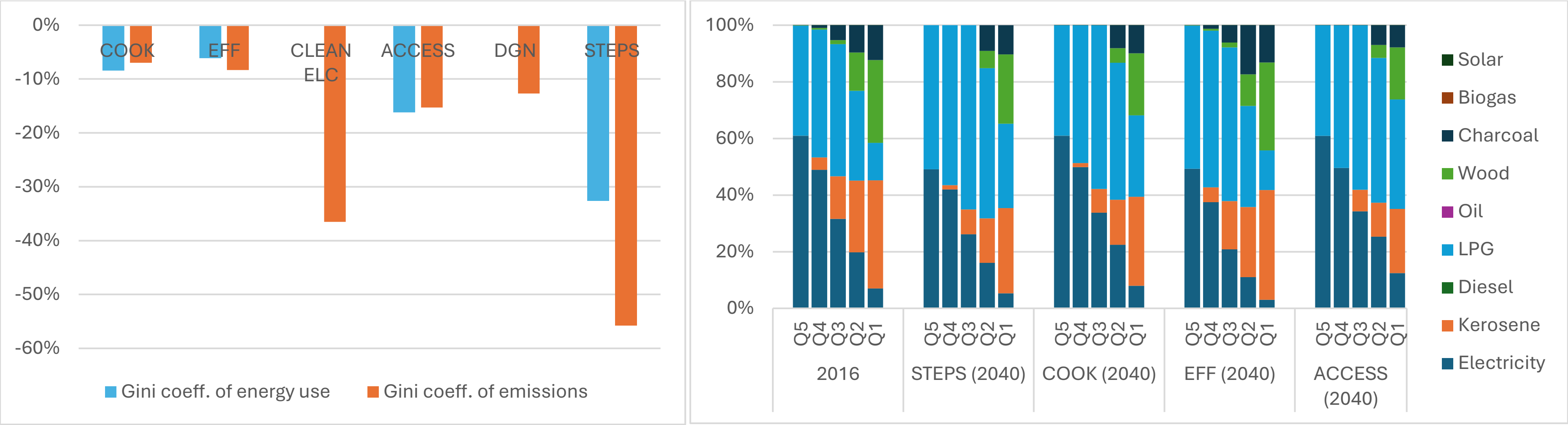


Figure 50. Effect of STEPS on Gini coefficients in 2040 (left panel) and household final energy share by energy carrier by income quintile (right panel), Nairobi. All Gini coefficients are calculated using useful energy.

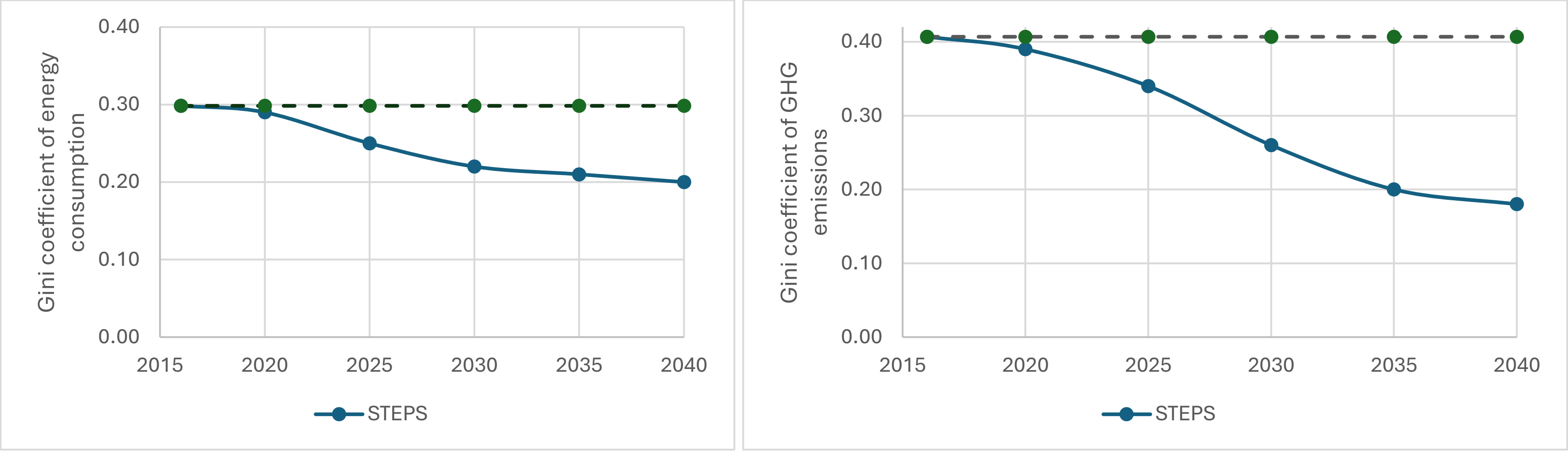


Figure 51. Gini projections of household energy use (left panel) and household GHG emissions (right panel), under the combined set of stated policies, Nairobi. All Gini coefficients are calculated using useful energy.

5.3.4. Yaoundé, Cameroon

Figure 52 illustrates the effect of STEPS on household energy consumption variations across different income quintiles in Yaoundé. Under the STEPS scenario, final household energy consumption sees a remarkable increase, tripling for the lowest income quintiles (Q1 and Q2) and nearly doubling for the higher income quintiles (Q4 and Q5). This also translates to an increase in the average household electricity consumption reaching approximately 1,300 kWh annually (an increase of 38% relative to the base year). While notable disparities in energy use between the upper- and lower-income quintiles persist, the ratio of energy consumption between these groups is nearly halved, signalling a meaningful reduction in overall energy inequality.

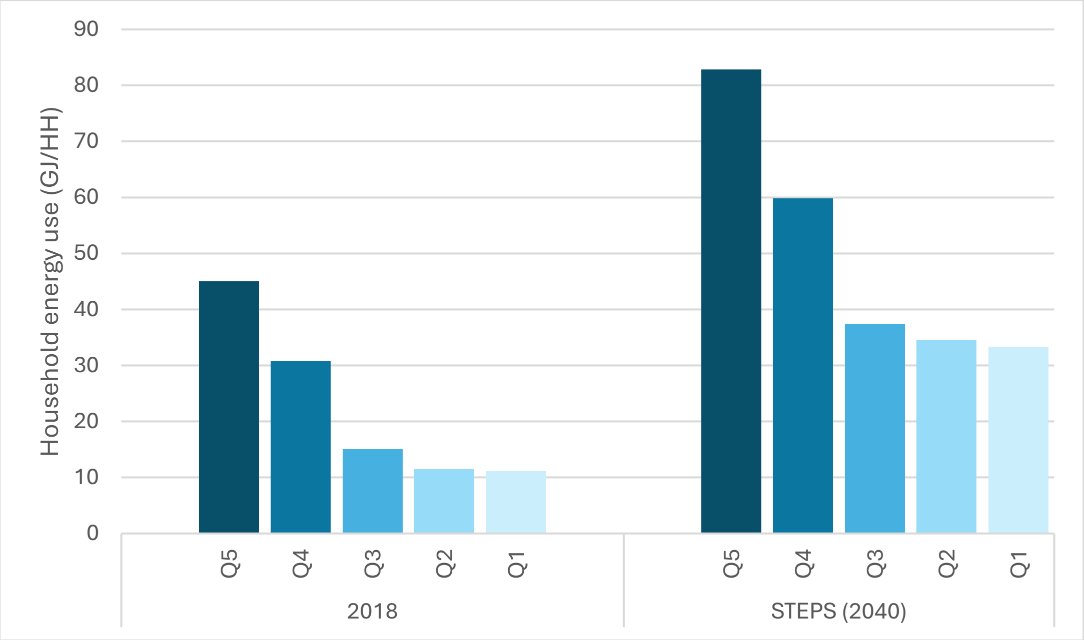


Figure 52. Annual household final energy use (GJ/household) by income quintile under selected policy interventions, Yaoundé.

In Yaoundé, the EFF PAM specified in the city's CAP have the most substantial positive impact on total final household energy use distributions, as shown in Figure 53. Given that Yaoundé had the second-highest level of electricity use inequality as a function of income in the base year, even modest efficiency improvements are particularly effective. These rather small targets significantly reduce electricity consumption in the higher income quintiles (Q4 and Q5) – see Figure 53b, which contributes to a 21% improvement in the Gini coefficient for household energy use.

Figure 53 also shows that ACCESS slightly widens the household energy use gap, leading to a 4% increase in the Gini coefficient of household energy use. The replacement of biomass with LPG, although more efficient overall, disproportionately benefits lower quintiles, thereby widening the gap in energy use. Also, although this intervention enables slightly higher electricity consumption among households in the lower income quintiles (Q1 and Q2), it also simultaneously grants those in the higher income quintiles (Q4 and Q5) broader access to more energy-intensive, electricity-dependent appliances that were previously not accessible.

The COOK intervention in Yaoundé only minimally reduces biomass usage in the lower income quintiles (Q1-Q3) due to the city's policy objective, which prioritizes the use of more efficient biomass cooking stoves over a complete fuel switch. Consequently, the COOK intervention does not significantly advance households into the higher tiers of the MTF for cooking.

In terms of emissions, the EFF intervention is the most effective, improving the Gini coefficient of GHG emissions by 22%. However, all the other interventions also contribute to non-negligible GHG emissions inequality reductions.

The cumulative effect of these policy measures, modelled in the STEPS scenario, leads to a notable decrease in the energy inequality Gini coefficient to 0.20 by 2040, which represents a 35% improvement from the base year. This scenario also markedly reduces household GHG emissions inequalities, achieving approximately a 64% reduction in the emissions Gini coefficient. Despite these gains, residual inequalities in both energy use and GHG emissions primarily stem from ongoing electricity and diesel use - Figure 53b. Notably, the upper 20% of households in Yaoundé still account for 42% of the total final electricity demand in 2040, a decrease from 52% in the base year (2017), highlighting persistent disparities that need addressing.

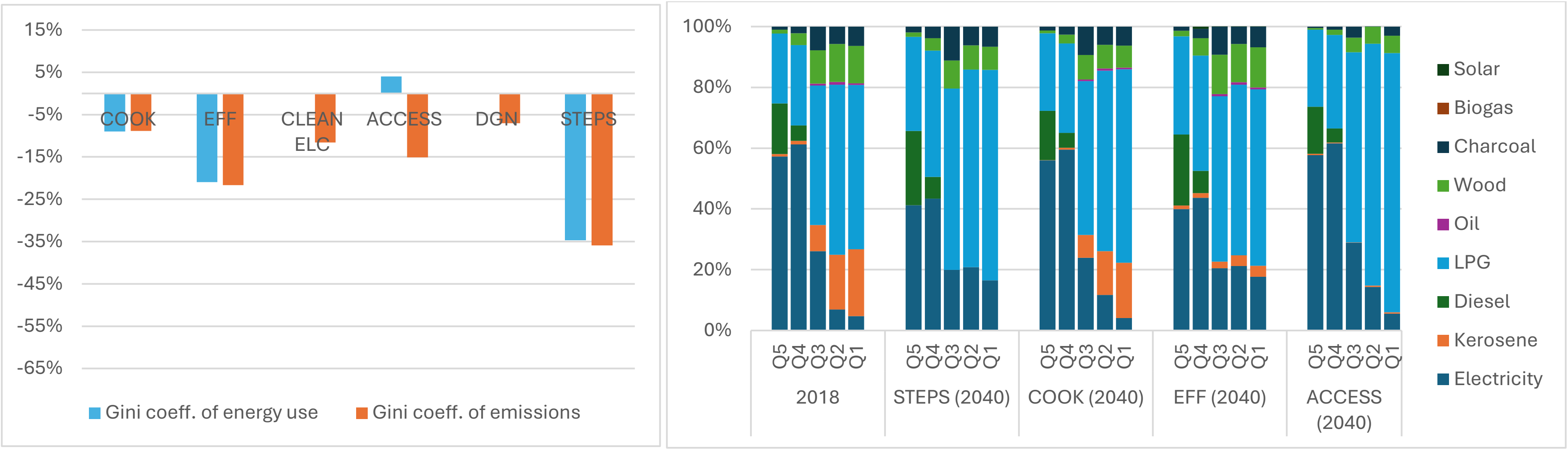


Figure 53. Effect of STEPS on Gini coefficients in 2040 (left panel) and household final energy share by energy carrier by income quintile (right panel), Yaoundé. All Gini coefficients are calculated using useful energy.

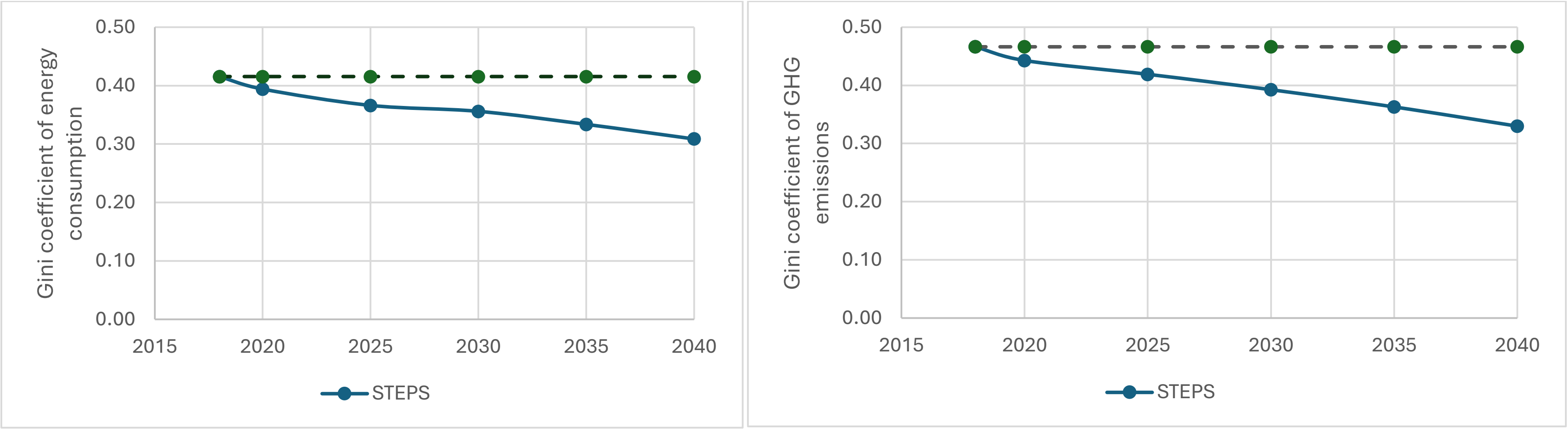


Figure 54. Gini projections of household energy use (left panel) and household GHG emissions (right panel), under the combined set of stated policies, Yaoundé. All Gini coefficients are calculated using useful energy.

5.3.5. Kasese, Uganda

Figure 55 show the effect STEPS on the quintile variations in household energy in Kasese. Under this scenario, households in Kasese see a slight increase in total final energy use, although less dramatically as in Cape Town, Nairobi or Yaoundé. Particularly notable is that average household electricity consumption increases more than sixfold from the base year, reaching over 1,200 kWh annually by 2040.

While there is a general modest improvement in the distribution of household energy use among the various quintiles, the gap between the highest (Q5) and lowest (Q1) income quintiles grows under the STEPS scenario. The energy divide, as indicated by the ratio of energy use between Q5 and Q1, expands from 1.88 in the base year to 2.53 in 2040 – see Table 12.

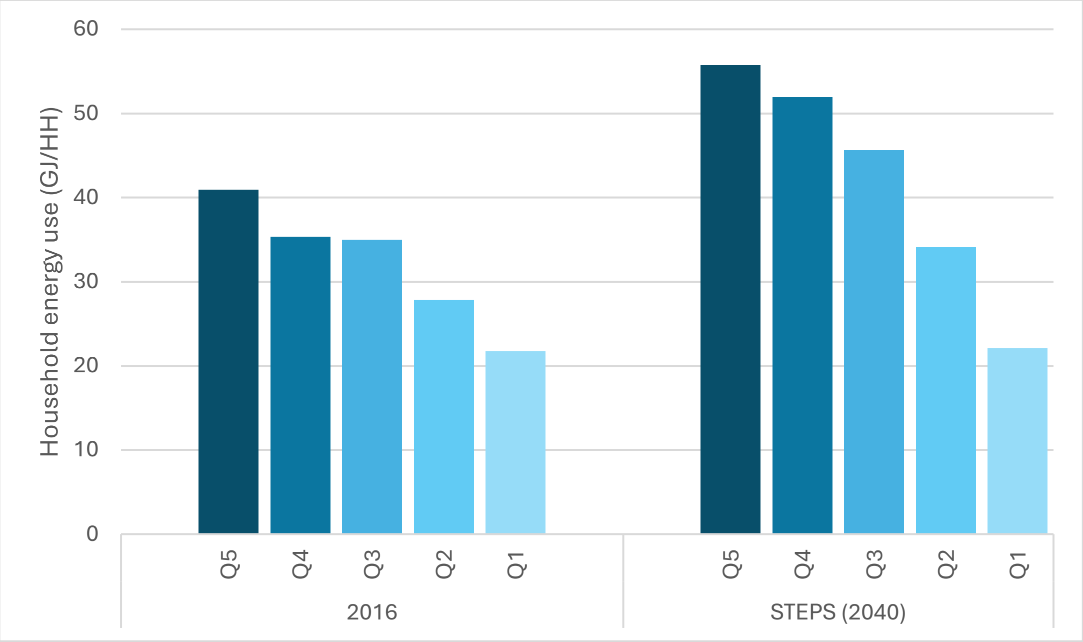


Figure 55. Annual household final energy use (GJ/household) by income quintile under selected policy interventions, Kasese.

Figure 56 and Figure 57 present the modelled impact of individual PAMs and STEPS on the Gini coefficients of energy consumption and GHG emissions in Kasese by 2040.

Similar to Tsevié, implementing ACCESS has the single biggest impact in reducing household energy use inequalities, reducing Gini coefficient by 26% relative to the BAU. ACCESS significantly increases access to modern fuels such as LPG and electricity, particularly in the upper income quintiles, although there is equally an overall drop in biomass usage.

The implementation of COOK as per Kasese's CAP increases energy use inequalities. Although the introduction of clean cooking technologies provides benefits by increasing access to cleaner fuels like LPG, and other electricity-dependent services, it also disproportionately facilitates higher energy consumption levels among wealthier households, thereby widening the energy use gap.

As a result, the combined impact of these PAMs in the STEPS scenario result in an overall increase in household energy use inequalities, increasing the Gini coefficient by 18% relative to the BAU. Also notable is that STEPS leads to a significant decrease in the share of biomass in household final energy demand from 97% in 2016 to 74% by 2040, while concurrently increasing the share of electricity in household energy use from 2% to 13% over the same period – see Table 12.

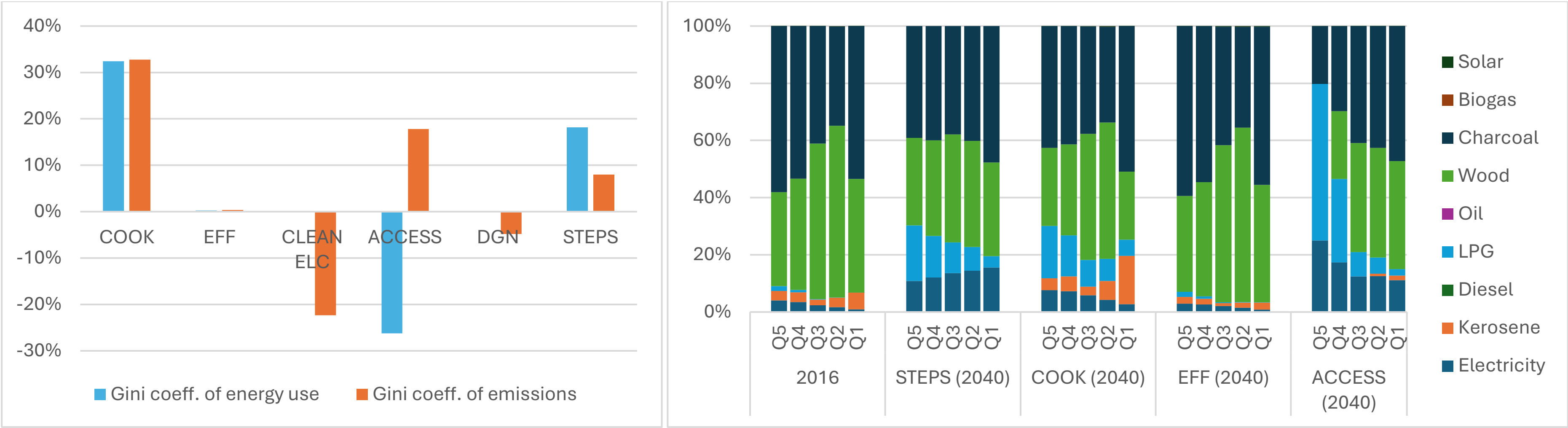


Figure 56. Effect of STEPS on Gini coefficients in 2040 (left panel) and household final energy share by energy carrier by income quintile (right panel), Kasese. All Gini coefficients are calculated using useful energy.

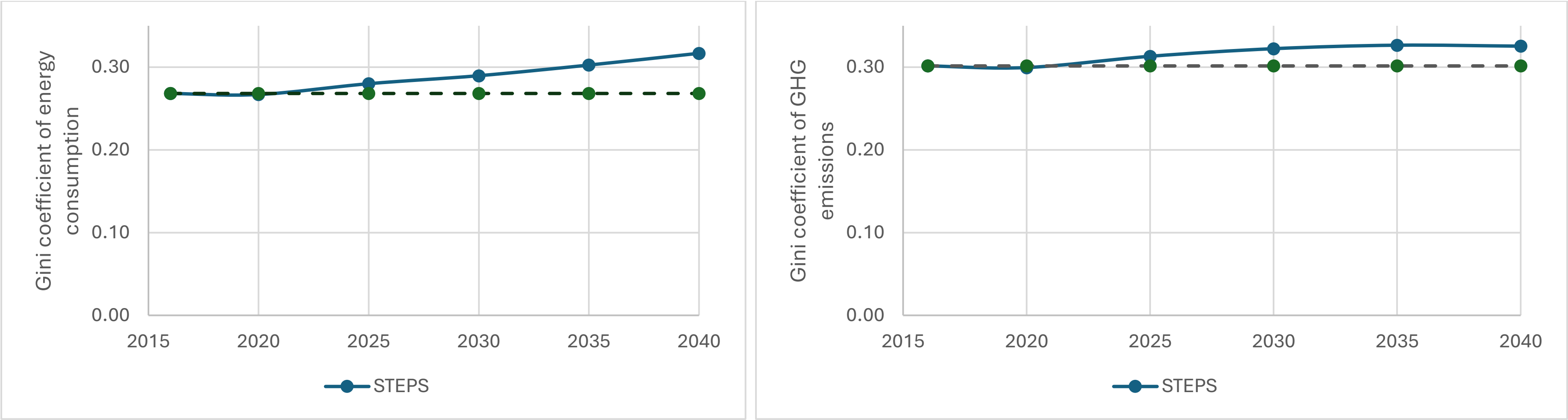


Figure 57. Gini projections of household energy use (left panel) and household GHG emissions (right panel), under the combined set of stated policies, Kasese. All Gini coefficients are calculated using useful energy.

5.3.6. Tsevié, Togo

Figure 58 illustrates the effect of STEPS on household energy consumption variations across different income quintiles in Tsévié by 2040. In ths scenario, there is no major shift in total final energy consumption across household quintiles, although the gap between the highest (Q5) and lowest (Q1) income quintiles does widen. Specifically, the Q5:Q1 ratio increases from 2.2 in 2017 to 2.83 in 2040. Despite this widening gap in energy use, Tsévié experiences the highest increase in average household electricity consumption among the study cities, soaring from 10 kWh in 2017 to 527 kWh/annum by 2040. This dramatic rise is largely attributable to the substantial number of previously unelectrified households gaining access to electricity under the ACCESS policy intervention.

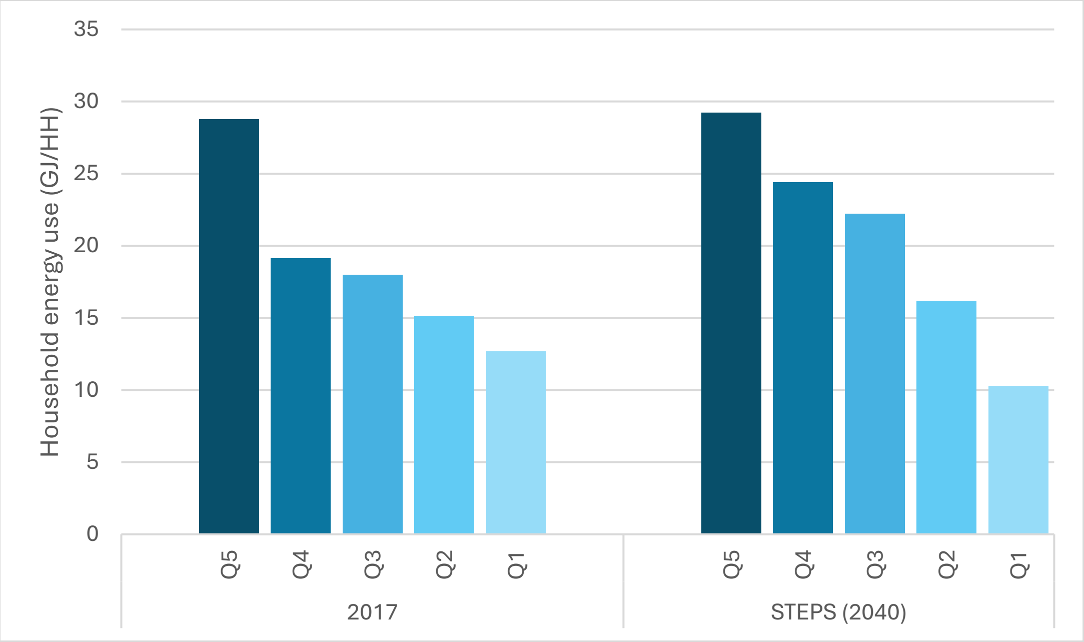


Figure 58. Annual household final energy use (GJ/household) by income quintile under selected policy interventions, Tsévié.

The analysis of the modelled PAMs for Tsevié, as depicted in Figure 59 and Figure 60 show the impacts of these interventions on the Gini of energy use and GHG emissions. Given Tsevié's status with low access to electricity in the base year, it is unsurprising that the ACCESS PAM has among the most substantial impact on reducing household energy use inequality, decreasing the Gini coefficient by 13% relative to the 2017 base year. ACCESS facilitates broader access to electricity and related energy services, significantly increasing the quantum of energy utilized by all households, particularly the upper quintiles - Figure 59b. Additionally, the ACCESS intervention introduces significant efficiency gains in Q4 and Q5, as these households substantially reduce their reliance on biomass, shifting towards LPG and electricity alternatives, hence the overall narrowing of the energy use ga under tis intervention.

The COOK intervention remarkably increases the Gini coefficient of energy use by 33%. Coupled with an electricity access starting from a low base, this policy intervention introduces large efficiency gains across all households, and particularly in lower-income quintiles, as they switch from the energy intensive use of biomass for cooking and water heating to more efficient biomass stoves, inadvertently shifting the balance of energy use towards wealthier households, thereby exacerbating the consumption distribution. Despite the COOK intervention significantly reducing the total amount of biomass used for cooking activities, all household quintiles in Tsevié remain in cooking poverty, as they continue to rely heavily on biomass for their energy needs. To effectively address cooking poverty, a clean cooking policy for Tsévié must set more ambitious targets, focusing on a complete fuel switch rather than merely replacing traditional biomass with more efficient alternatives.

From an emissions standpoint, CLEAN ELC achieves the highest impacts in terms of reducing GHG emissions inequalities, reducing the Gini coefficient by 20% relative to the base year.

Implementing all the selected PAMs under the STEPS scenario could see an overall modest increase in household energy inequalities in Tsevié by 8% by 2040. However, this would come with a trade-off, as emissions inequalities, as evidenced by the Gini coefficient would reduce by 17% relative to the base year during that same time. Despite the continued pronounced use of biomass in the STEPS scenario, households across different quintiles gain access to modern fuels like electricity and LPG that deliver other immense benefits in addition to the positive impact on the environment.

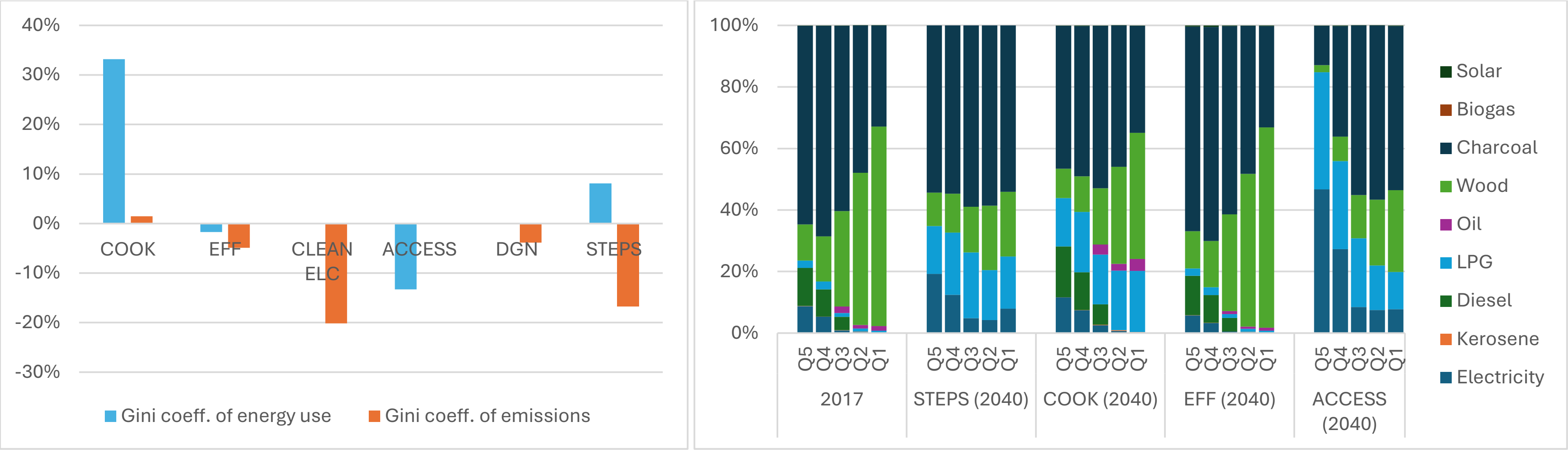


Figure 59. Effect of STEPS on Gini coefficients in 2040 (left panel) and household final energy share by energy carrier by income quintile (right panel), Tsévié. All Gini coefficients are calculated using useful energy.

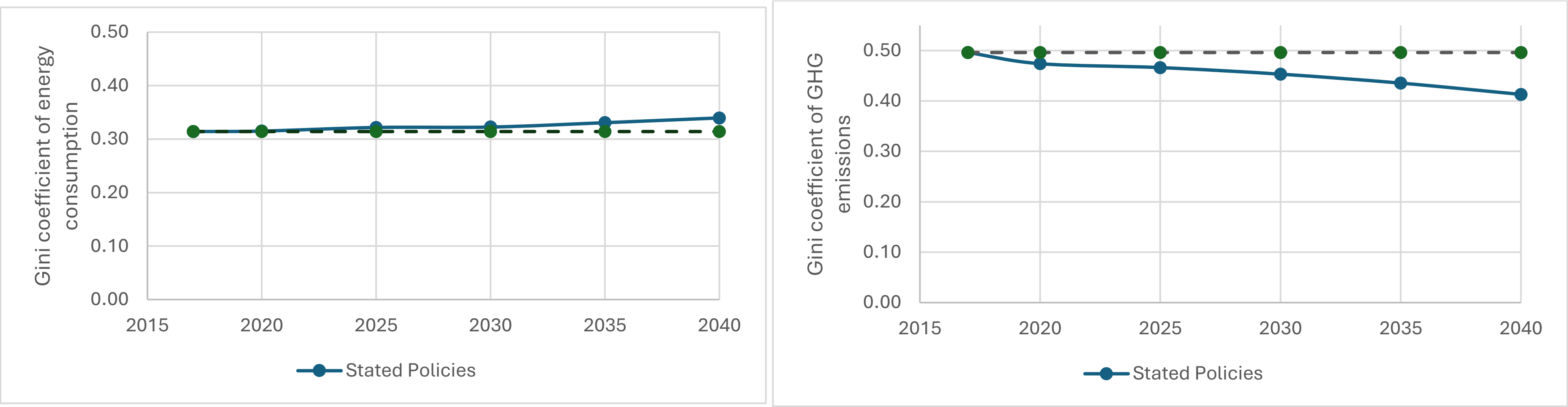


Figure 60. Gini projections of household energy use (left panel) and household GHG emissions (right panel), under the combined set of stated policies, Tsevié. All Gini coefficients are calculated using useful energy.

5.4. Summary of findings of Chapter 5

This chapter's analysis of stated energy policies (STEPS) across six African cities reveals both promising pathways and persistent challenges in addressing household energy inequalities. The modelling results demonstrate that while current policies were not explicitly designed with equity objectives, they generally yield positive impacts on energy distribution patterns, though with notable variations across cities and interventions.

Several key findings emerge from this analysis:

First, the effectiveness of policy interventions varies significantly across urban contexts, even when targeting similar objectives. Clean cooking initiatives and electricity access programs emerge as the most impactful interventions for reducing household energy use inequalities in most cities. For instance, in Dakar, clean cooking measures alone could reduce the Gini coefficient for household energy use by 32%. However, these same interventions sometimes produce counterintuitive results, as seen in Kasese and Tsevié, where efficiency gains in lower-income households paradoxically appear to widen energy use gaps.

Second, grid decarbonization consistently proves most effective in reducing household emissions inequalities across all cities. This finding is particularly significant in cities with carbon-intensive electricity supplies and high base year inequalities in electricity consumption. The results suggest that clean electricity initiatives could reduce emissions Gini coefficients by 20-37% across the studied cities.

Third, the analysis reveals that while STEPS generally improve overall energy equity metrics, they often fall short in addressing specific disparities, particularly in electricity access and utilization. Even under successful policy implementation scenarios, significant disparities persist. For example, in Dakar, despite substantial improvements, the wealthiest quintile would still account for 45% of total household electricity consumption by 2040.

Fourth, the modelling demonstrates important trade-offs between different policy objectives. Some interventions that effectively reduce emissions inequalities may simultaneously exacerbate energy use disparities, as seen in Tsevié, where STEPS could reduce emissions inequalities by 17% while increasing energy use inequalities by 8%.

Fifth, the analysis highlights the critical role of local context in determining policy outcomes. Cities with higher base year access to modern energy services, like Cape Town, show more modest equity improvements from new interventions compared to cities starting from a low base, such as Kasese and Tsevié, where similar policies yield more dramatic changes in energy consumption patterns.

These findings have important implications for urban energy policy design in Africa. While current stated policies show promise in reducing overall energy and emissions inequalities, achieving more equitable outcomes may require:

1. More explicit incorporation of equity considerations in policy design
2. Better targeting of interventions to address persistent disparities in electricity access and use
3. Context-specific policy approaches that account for varying base year conditions and institutional capacities
4. Careful consideration of potential trade-offs between different policy objectives

Looking ahead, these results suggest that while current policies provide a foundation for improving energy equity, more targeted interventions may be needed to address persistent disparities in urban household energy systems. Future policy development should consider not just aggregate improvements in energy access and emissions reductions, but also the distributional impacts across different household income groups.

The next chapter will build on these findings by examining more ambitious policy scenarios designed to explicitly address energy equity objectives, providing insights into potential pathways for achieving more equitable urban energy transitions in Africa.

Chapter 6 : Modelling Alternative Pathways to a Just Urban Energy Transition

Building on Chapter 5's evaluation of stated policy interventions (STEPS), which revealed certain gaps and potential misalignments with equity objectives, this chapter develops and analyses two alternative scenarios – Blues and Harmony – specifically designed through an equity lens. While STEPS represents current policy commitments and stated plans, Blues and Harmony explore more transformative pathways i.e. Blues emphasizes bottom-up, community-driven approaches to a just urban energy transition, while Harmony focuses on top-down, municipal-led initiatives. Using the UHEM model developed in Chapter 3, this chapter quantitatively assesses how these alternative scenarios could impact household energy use and emissions inequalities across the six study cities. The analysis particularly examines whether more ambitious clean energy targets, combined with various redistributive mechanisms, could deliver better equality outcomes compared to the baseline trajectory represented by STEPS. This comparative assessment provides insights into potential policy recalibrations that could better align energy transition pathways with equity objectives in African urban contexts.

The analysis presented in this chapter therefore provides evidence to answer research question 4 of this thesis: "How can alternative pathways, beyond those stated in existing plans, contribute to energy access and stimulate urban economic development, while ensuring that local energy transitions promote equity in urban contexts?"

6.1. Scenario design

This section describes two possible narrative futures scenarios - Harmony and Blues – in contrast with current policy commitments, as modelled in the STEPS scenario. Central to the formulation of these alternative pathways is sustainable development and justice, measured through reduced energy and emissions inequalities. More specifically, Harmony describes a top-down approach to solving the inequality issue, which translates to generally more ambitious municipal-led targets relative to the STEPS scenario. Blues on the other hand is rather a bottom-up approach, challenging the status quo, with a particular emphasis on grassroot initiatives.

The scenario design framework (Figure 61) positions Blues and Harmony relative to STEPS along two key dimensions: governance approach (bottom-up to top-down) and ambition level (low to high). While STEPS represents current policy commitments with moderate ambition levels and a blended approach to governance (i.e. bottom up and top-down), Blues and Harmony explore more ambitious pathways with contrasting governance approaches. Blues emphasizes community-led initiatives and distributed planning, while Harmony focuses on municipal leadership and centralized planning.

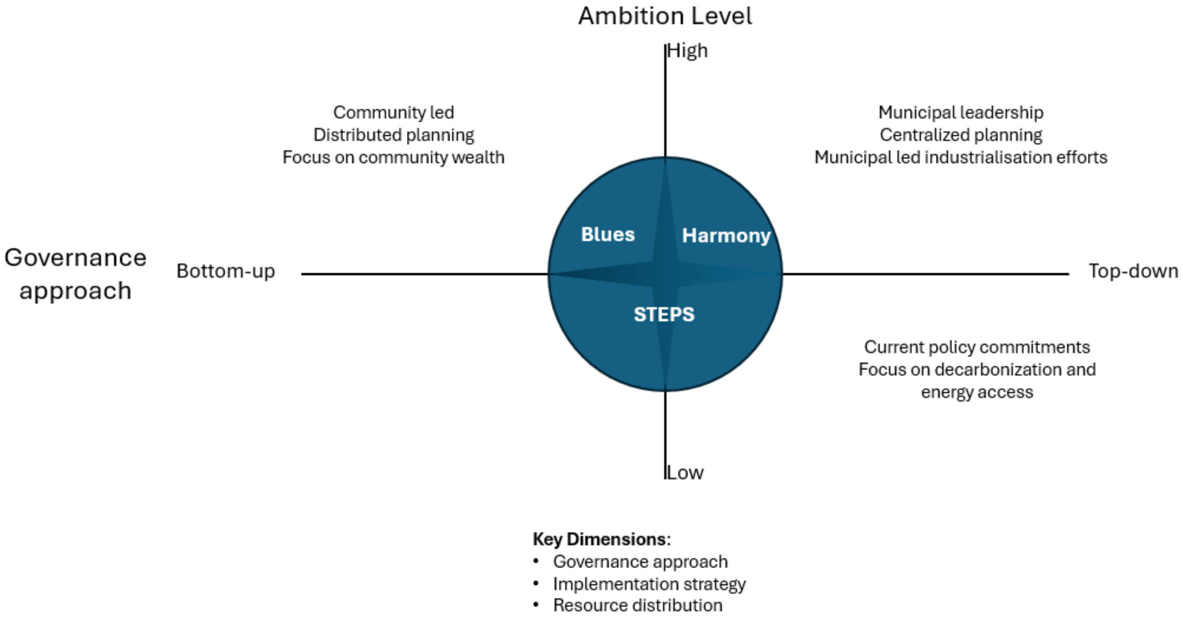


Figure 61: Scenario design framework

6.1.1. Scenario storylines

STEPS scenario revisited

The STEPS scenario, analysed in detail in Chapter 5, represents current policy commitments outlined in the cities' energy strategies and climate action plans. It therefore represents the baseline against which the two other scenarios (Blues and Harmony – described further below) are assessed for their effectiveness. In the STEPS scenario, the cities pursue emission reductions and improved energy access through practical, incremental measures rather than equity-driven policies. They channel investments into renewable energy -particularly distributed solar and storage – for municipal and public facilities, while complementing these initiatives with modest yet meaningful energy efficiency efforts like LED lighting and more efficient appliances.

Transportation decarbonization progresses through the gradual electrification of vehicles and the expansion of mass transit systems, showcasing the cities' limited but deliberate interventions. At the same time, energy access steadily improves through extending grid coverage to underserved communities and deploying decentralized solutions, providing affordable, reliable energy without explicitly emphasizing fair outcomes for all stakeholders. These interventions reflect a moderate level of ambition and employ a blended governance approach that combines both top-down municipal leadership and bottom-up community initiatives, as denoted by STEPS' positioning in Figure 61, working within existing institutional frameworks to achieve the goals set out in the CAPs.

6.1.1.1. Blues scenario

Premise: Blues represents a bottom-up transformation where community empowerment drives the energy transition.

The Blues scenario is a future where a cadence of ambition, equity, and sustainability resounds with the rhythmic vibes of **energy democracy (**see working definition in section 2.6.1). In this transformative narrative, the central theme is the empowerment of every individual to shape the urban energy landscape.

Guiding this transformation is **empowered citizenry** who understand the rhythm of energy democracy. Their motto reflects a commitment to inclusivity, where every voice matters. Local communities, previously silenced, are now the composers of the cities' energy transition agenda. Through **open dialogues and participatory decision-making processes**, the roadmaps to sustainability are forged, embracing the diversity of needs and aspirations that characterize these dynamic urban communities.

To initiate this transformative process, a pivotal element is the immediate focus and implementation of a comprehensive program for **education and skills training**. By equipping communities with the knowledge and tools to actively participate in the decarbonized economy, they can become stakeholders in the process of positive change. This focus on skills development ensures that the energy transition brings about not only environmental sustainability but also socio-economic empowerment for all.

To reflect these urban communities' development aspirations for industrialization, employment, higher incomes, prosperity, and economic transformation, they wholeheartedly **embrace ambitious modern energy targets**. Specifically, they aim for a minimum annual electricity consumption of 1000 kWh per capita.

Dancing to this rhythm of collective and ambitious bottom-up participation, a tapestry of **distributed energy systems and community energy projects** adorn the landscape, complementing the main grid and strategically deployed to support underserved communities. Collaborative efforts between the affluent and the less privileged set up an **altruistic energy exchange mechanism**, nurturing unity in prosperity. These are supported by conducive regulations and mechanisms such as time of use (TOU) tariffs, feed-in-tariffs, or tax incentives, fostering private sector participation and the widespread deployment of decentralized energy systems.

Similar to energy projects, community-driven initiatives lead to the development of **localized transportation services** including neighbourhood car-sharing programs, community-operated shuttles, or shared bicycle networks that prioritize accessible and affordable transportation.

Recognizing the pivotal role of **private investment**, **entrepreneurial spirits** are invited to take their place in the ensemble, infusing their resources into the rhythm of progress. With carefully designed incentives and innovative financing models, the scenario orchestrates a symposium where private capital and communal aspirations amplify the cadence of change and accelerate the transformation to a just, equitable, and sustainable energy landscape.

Limitations of this scenario

The Blues scenario's success relies heavily on several critical conditions that, if absent, could impede its realization. First, it assumes a high level of social cohesion and community organization that may not exist in all urban contexts, particularly in areas with significant social fragmentation or weak civil society structures. Second, the scenario depends on sufficient financial resources and technical capacity within communities to implement and maintain distributed energy systems – a challenge in resource-constrained environments. Third, it requires regulatory frameworks that enable community-led energy initiatives, which may be difficult to achieve in contexts where centralized utilities hold strong monopolies or where existing legislation restricts decentralized energy development. Fourth, the assumption of altruistic collaboration between affluent and less privileged communities might prove optimistic in cities with deeply entrenched socio-economic divisions. Finally, the scenario's success hinges on sustained community engagement and participation over long periods, which can be difficult to maintain, especially if early initiatives fail to deliver tangible benefits or if competing priorities emerge. These limitations suggest that the Blues scenario might be more feasible in contexts with strong social capital, supportive regulatory environments, and access to sufficient technical and financial resources.

6.1.1.2. Harmony scenario

Premise: Harmony represents a top-down transformation led by municipal authorities with strong institutional coordination.

Harmony unfolds as a world where African municipal authorities take the stage, leveraging their political impetus and resources to pioneer a truly just energy transition for their city.

The energy transition orchestrated by these visionary municipal leaders is far from fanciful; it's a meticulous symphony guided by **data-driven strategies**. Complex monitoring systems are put in place to track crucial metrics such as energy poverty, health, employment, air quality, and other economic and environmental indicators. This data confers upon decision-makers the power of informed choices, ensuring that policies and interventions harmonize with the specific needs of vulnerable communities.

Political engagement is high, lending steadfast support to municipal governments as they orchestrate robust measures for amplifying the share of renewable energy in the primary energy mix, through a mix of centralised and decentralised energy resources. This is also made possible through **regional cooperation** across municipal borders, for the optimal use of locally available resources to ensure energy security.

In this symphony, the agriculture and livestock sectors experience a revolutionary transformation into well-established small-scale industries. Cutting-edge technologies are leveraged to enhance **efficiency and sustainability in farming practices**, and innovative agro-processing ventures thrive, creating employment opportunities for the local population. In the transport sector, these municipal visionary leaders invest heavily in **public mass transit systems** and **electrified rail networks**. These systems are expanded several folds to accommodate the population increase and mitigate the rise in car traffic resulting from the increase in personal vehicles and to keep the public share of passenger km high and energy demand relatively low. By providing efficient and sustainable mass transit options, the cities not only reduce emissions but also enhance accessibility for all, particularly the less privileged.

Economic productivity increases substantially across all the productive use sectors (i.e. commercial, industrial and agricultural) in turn spurring the local energy demand several fold, as is the case with any competitive prosperous economy. This remarkable growth in energy demand is principally met by efficient and distributed energy resources, as well as new energy transaction mechanisms such as wheeling.

In this scenario of just energy transition, success is driven by targeted income redistribution mechanisms such as direct cash transfers, progressive taxation, and other financial tools aimed at reducing income inequality. These measures are supported by national governments and bolstered by international financial contributions. Additional resources include the establishment of local financial institutions, the issuance of green bonds, and strategic public-private partnerships that foster collaboration and accelerate the reduction of income disparities, ensuring a more balanced and just economic landscape.

Limitations of this scenario

The Harmony scenario faces several significant constraints that could impede its implementation. First, it assumes strong municipal authority and institutional capacity that many African cities currently lack, particularly in contexts where energy governance remains heavily centralized at the national level. Second, the scenario's success depends on sustained political will and coordination across multiple levels of government, which can be challenging given electoral cycles and changing political priorities. Third, the substantial financial requirements for large-scale infrastructure projects (like electrified rail networks and mass transit systems) may be beyond the fiscal capacity of many municipalities, especially without consistent support from national governments and international partners. Fourth, the assumption of effective data collection and monitoring systems requires technical expertise and resources that are often scarce in municipal governments. Fifth, the success of income redistribution mechanisms relies on national government buy-in and effective tax collection systems, which can be challenging in contexts with large informal economies. Finally, the scenario assumes strong regional cooperation and cross-border resource sharing, which may be difficult to achieve in areas with political tensions or competing municipal interests. These limitations suggest that the Harmony scenario might be more feasible in larger, well-resourced cities with strong institutional frameworks and significant political autonomy.

6.1.2. Implementation of Blues and Harmony in UHEM Model

While Blues and Harmony present global visions for urban transformation, their operationalisation in the UHEM model focuses specifically on the residential sector. This focused scope allows for quantitative assessment of how different governance approaches to energy transition impact household energy equity, while acknowledging that the full transformative potential of these scenarios extends beyond the household sector.

The broader scenario narratives are translated into specific modelling parameters in four key intervention areas (in a similar approach to STEPS – see Table 11):

First, regarding energy efficiency, both scenarios advance beyond STEPS in technology adoption rates and appliance efficiency, but through distinctly different mechanisms. Blues, true to its bottom-up philosophy, envisages more ambitious adoption rates as is common with the bottom-up driven nature of the diffusion of efficient technologies, particularly in communities where social cohesion facilitates rapid knowledge sharing. Harmony, while also ambitious, implements efficiency improvements through structured municipal programs and regulatory frameworks, resulting in more uniform but potentially slower adoption patterns.

Second, regarding clean energy access, both scenarios maintain STEPS' commitment to universal electricity access by 2030 but diverge from STEPS in implementation approaches. Blues emphasizes distributed generation and community-owned energy projects, enabling localities to manage their energy resources independently. This approach results in a higher penetration of rooftop solar and distributed forms of generation, particularly in Q4 and Q5 income quintiles where investment capacity is stronger. In contrast, Harmony pursues centralized planning and systematic deployment of grid infrastructure, ensuring more uniform access patterns across income groups through municipal coordination.

Third, the scenarios present distinct pathways for clean cooking transitions. Harmony builds incrementally upon STEPS targets, implementing structured programs for clean cooking adoption. Blues, however, takes a more transformative approach with respect to STEPS, positing that, given the right conditions, market forces would be enough to drive the large-scale adoption of electric cooking across all income segments.

Fourth, in power sector decarbonization, the scenarios diverge significantly from each other. Blues maintains STEPS' decarbonization targets, which were broadly aligned with country-specific NDC targets, reflecting the reality that grid-level transformations often exceed community-level influence. Harmony, leveraging municipal authority and regional cooperation, pursues significantly higher ambition levels for grid decarbonization through coordinated infrastructure planning and investment.

Table 13 provides a detailed overview of how these scenarios are implemented within the UHEM model, specifically how the qualitative narratives were translated into quantitative parameters, enabling direct comparison with STEPS.

Key intervention area		**Blues Scenario**	**Harmony Scenario**
Energy Efficiency	Lighting	Complete phase-out of traditional lighting (CFL, incandescent)	Phase-out of traditional lighting following municipal timelines
		100% LED adoption across all quintiles	100% LED adoption across all quintiles
		Elimination of backup lighting systems (diesel/petrol generators)	
	Heating and cooling	Accelerated adoption of cooling and (and heating appliances only in Cape Town) driven by calculated based off the increased electricity access rates, urbanisation rates and cooling (and heating) demand using equations 8-13 in the methods chapter	Where targets on cooling appliances exist in STEPS, those were maintained
			More ambitious adoptions in Q4 and Q5 relative to STEPS (by ~20% on average)

	Other appliances (TV, fridge, washing machine)	Diffusion model in equations 8-13 used to determine the pace and scale of penetration based off income, electricity access, and urbanisation rate	Where targets on other electrical appliances exist in STEPS, those are maintained
Energy access	Distributed Generation	Double STEPS' Distributed generation (DG) penetration targets	Maintains STEPS' DG targets
		More rapid DG adoption in Q4-Q5 based off current global trends (2-4 years lead on Q1-Q3 on average)	More uniform distribution across Q1-Q5 relative to STEPS
	Clean cooking	Complete transition to electric cooking by 2040	Phase-out of solid fuels
		Diffusion model in equations 8-13 used to determine the pace and scale of penetration based off income, electricity access, and urbanisation rate	LPG as primary transition fuel
		The transition in lower-income quintiles progresses more gradually compared to the swifter adoption by wealthier households.	Modest electric cooking adoption in Q4-Q5
	Electrification	STEPS target of universal electrification goals by 2030 is maintained	STEPS target of universal electrification goals by 2030 is maintained
Grid Decarbonization		Maintains STEPS' emissions reduction targets	Doubling of STEPS' emission reduction targets

Table 13. Description of implementation of Blues and Harmony in the UHEM model

6.2. Impact analysis of Blues and Harmony

This section presents the model findings for the Blues and Harmony simulations, focusing on the changes in key metrics such as the Gini coefficients under different constraints, and comparing these results against the baseline - STEPS scenario.

Table 14 shows a snapshot in 2040 of key inequality and sustainability indicators across the STEPS, Blues and Harmony scenarios, and the base year, encompassing social, economic, and environmental dimensions. The analysis of these indicators is presented in the following sections.

		Cities					
Indicator	Units	Dakar	Cape Town	Nairobi	Yaoundé IV	Kasese	Tsévié
Social Dimension							
Gini coeff of household energy use – **Base year**		0.27	0.42	0.30	0.42	0.27	0.31
Gini coeff of household energy use - **STEPS**		0.15	0.39	0.20	0.31	0.32	0.34
Gini coeff of household energy use - **BLUES**		0.18	0.17	0.27	0.34	0.08	0.29
Gini coeff of household energy use - **HARMONY**		0.19	0.32	0.32	0.27	0.37	0.39
Share of population with electricity - **Base year**	%	94%	98%	97%	95%	48%	24%

Share of population with electricity - **STEPS**	%	100%	100%	100%	100%	100%	100%
Share of population with electricity - **BLUES**	%	100%	100%	100%	100%	100%	100%
Share of population with electricity - **HARMONY**	%	100%	100%	100%	100%	100%	100%
Share of biomass on household total energy demand - **Base year**	%	45%	0%	8%	18%	97%	95%
Share of biomass on household total energy demand - **STEPS**	%	35%	0%	6%	10%	74%	71%
Share of biomass on household total energy demand - **BLUES**		0%	0%	0%	0%	0%	0%
Share of biomass on household total energy demand - **HARMONY**		0%	0%	0%	0%	0%	0%
Share of electricity on household total energy demand - **Base year**	%	26.0%	91.0%	22.0%	23.0%	2.0%	4.0%
Share of electricity on household total energy demand - **STEPS**	%	22.8%	98.9%	41.7%	32.4%	12.8%	11.0%
Share of electricity on household total energy demand - **BLUES**		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Share of electricity on household total energy demand - **HARMONY**		35.6%	99.9%	40.6%	32.7%	47.2%	47.2%
Top 20% (Q5) share of total final household energy use - **Base year**	%	29%	50%	32%	40%	25%	31%
Top 20% (Q5) share of total final household energy use - **STEPS**	%	20%	29%	32%	33%	24%	29%
Top 20% (Q5) share of total final household energy use - **BLUES**		21%	20%	25%	26%	17%	20%
Top 20% (Q5) share of total final household energy use - **HARMONY**		21%	29%	29%	45%	29%	33%
Economic Dimension							
Household energy use ratio between Q5 and Q1 - **Base year**		1.94	4.39	2.06	4.06	1.88	2.20
Household energy use ratio between Q5 and Q1 - **STEPS**		0.92	3.09	2.65	2.49	2.53	2.83
Household energy use ratio between Q5 and Q1 - **BLUES**		1.33	1.79	1.64	4.48	0.78	2.28
Household energy use ratio between Q5 and Q1 - **HARMONY**		1.19	2.98	2.33	2.07	3.82	3.19
Average household electricity consumption - **Base year**	kWh	860	3059	351	939	203	177
Average household electricity consumption - **STEPS**	kWh	2538	3665	473	1300	1238	527
Average household electricity consumption - **BLUES**	kWh	5601	5181	4905	4689	5845	5604

Average household electricity consumption - **HARMONY**	kWh	2443	3544	573	1318	1547	742
Environmental Dimension							
Gini coeff of household GHG emissions - **Base year**		0.41	0.43	0.41	0.47	0.30	0.50
Gini coeff of household GHG emissions - **STEPS**		0.29	0.23	0.20	0.33	0.33	0.41
Gini coeff of household GHG emissions - **BLUES**		0.13	0.15	0.31	0.33	0.19	0.24
Gini coeff of household GHG emissions - **HARMONY**		0.25	0.43	0.38	0.29	0.37	0.44
Top 20% (Q5) share of total household GHG emissions - **Base year**	%	41%	51%	40%	44%	29%	47%
Top 20% (Q5) share of total household GHG emissions - **STEPS**	%	30%	33%	39%	36%	28%	37%
Top 20% (Q5) share of total household GHG emissions - **BLUES**		21%	18%	27%	26%	16%	18%
Top 20% (Q5) share of total household GHG emissions - **HARMONY**		29%	30%	35%	34%	28%	38%
Household GHG emissions ratio between Q5 and Q1 - **Base year**		9.54	6.40	5.74	9.79	3.19	12.07
Household GHG emissions ratio between Q5 and Q1 - **STEPS**		2.76	3.30	6.22	2.97	2.96	4.35
Household GHG emissions ratio between Q5 and Q1 - **BLUES**		1.33	1.86	4.07	5.82	0.90	4.00
Household GHG emissions ratio between Q5 and Q1 - **HARMONY**		1.70	9.11	3.91	2.43	4.07	5.48

Table 14. Indicators of energy sustainability under the STEPS, Blues and Harmony scenarios by 2040

Blues and Harmony result in varied outcomes across the studied cities. Both scenarios drive significant increases in electricity's share of household energy mix compared to the baseline - STEPS (Figure 62). The Blues scenario achieves complete electrification of household energy demand across all cities, representing the most ambitious transformation. Harmony also shows substantial progress, particularly in smaller cities - notably in Kasese and Tsévié, where electricity's share increases from 12.8% and 11.0% in STEPS to 47.2% in both cities under Harmony, with the remaining demand met by LPG.

While both scenarios increase electricity's share in the energy mix, they differ markedly in their impact on absolute electricity consumption, as shown in Figure 62. The Blues scenario naturally drives substantial increases in average household electricity consumption, with final demand in 2040 ranging from 4,950 kWh in Nairobi to over 5,800 kWh in Kasese. These levels significantly exceed both the IEA's 1,250 kWh and Rockefeller Foundation's 1,000 kWh benchmarks for decent living standards. In contrast, Harmony's electricity consumption levels remain closer to the baseline projections in the STEPS scenario – for example, in Dakar, consumption under Harmony (2,443 kWh) is nearly identical to STEPS (2,538 kWh), suggesting that its increased share of electricity comes primarily from reduced total energy consumption rather than increased electrical load.

Smaller cities, starting from lower base year values, demonstrate the most dramatic increases in electricity use, which naturally, experienced a greater share of their energy demand being electrified. In Kasese, average household electricity consumption surges from 1,238 kWh under STEPS to 5845 kWh under Blues, representing a 372% increase. Similarly, Tsévié sees a remarkable growth in electricity demand from 527 kWh to 5,604 kWh, a more than tenfold increase. These changes far outpace the more modest increases observed in larger cities - for instance, Cape Town's increase from 3,665 kWh to 5,181 kWh represents only a 41% change. Also, across all six cities, lower-income quintiles experienced the biggest jumps in electricity consumption compared to higher-income quintiles, highlighting the equality benefits of clean electricity access policies.

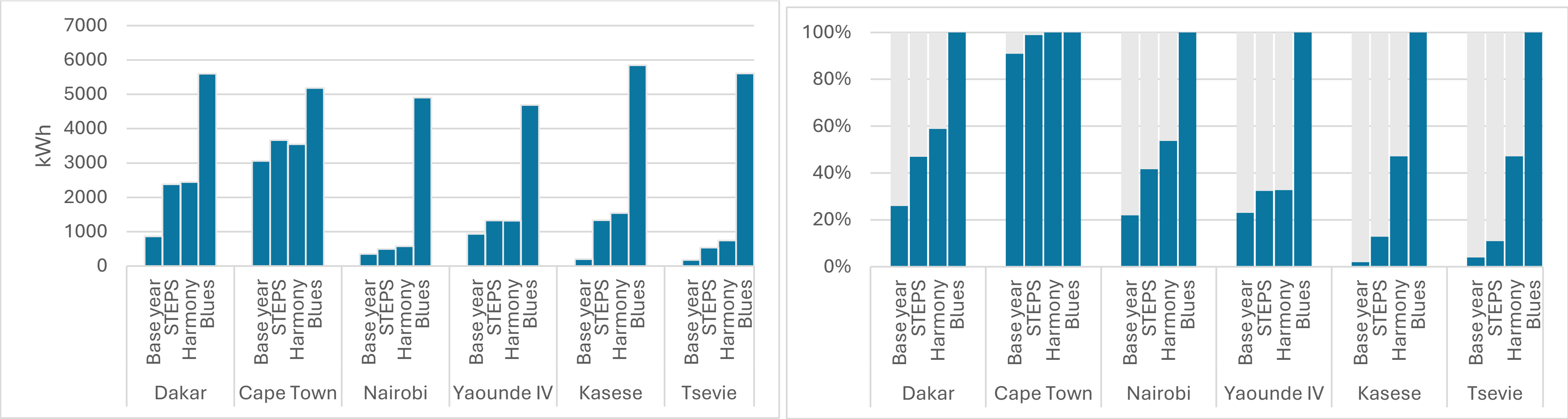


Figure 62. Average household final electricity consumption (left panel) and shares of electricity in final household energy (right panel) under all scenarios in 2040.
All Gini coefficients are calculated using useful energy.

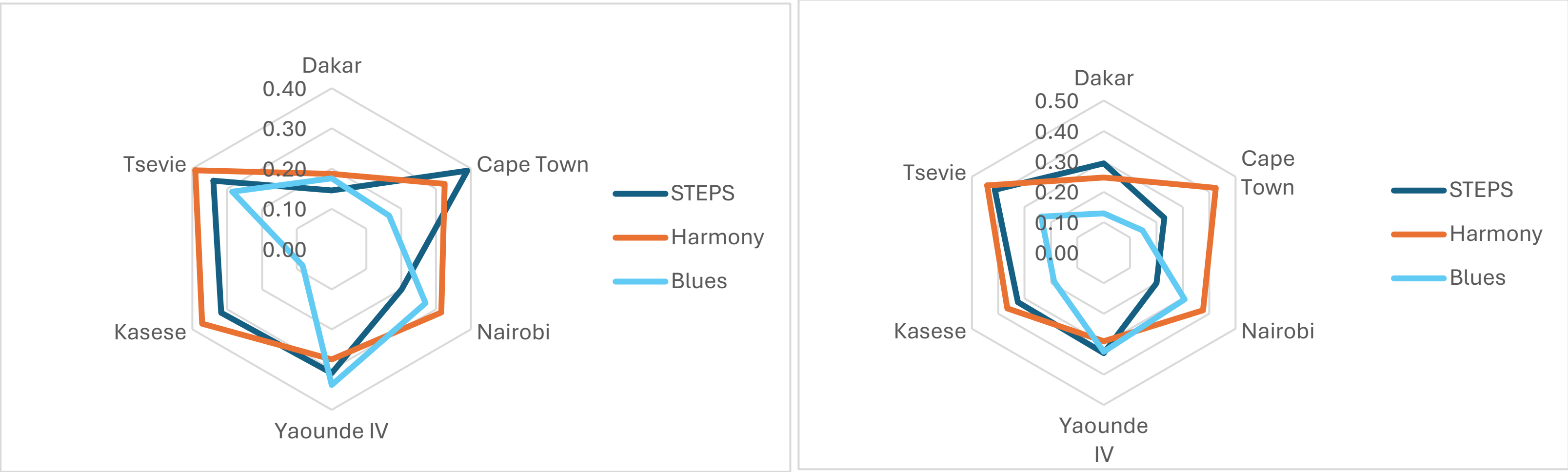


Figure 63. Comparative analysis of the effect of all three scenarios on the Gini coefficient of household energy use (left panel) and Gini coefficient of household GHG emissions (right panel) in 2040.
(0 = Perfect equality, 1 = Maximal inequality). All Gini coefficients are calculated using useful energy.

Total energy demand on the other hand shows a different pattern. Total energy demand in both Blues and Harmony scenarios generally decreases compared to STEPS, highlighting significant efficiency gains from fuel switching. Nairobi, however, is one notable exception showing increased final energy demand ranging from 15% to 100% across income quintiles, likely reflecting suppressed demand in the base year – see Figure 64. Efficiency gains are most pronounced in Yaoundé, Kasese and Tsévié, where demand across some household quintiles dropped by up to 75% compared to STEPS. These understandably are also the cities with the highest shares of biomass use in the base year.

Despite these efficiency improvements, significant variations in total household energy consumption persist across cities under both scenarios, similar to patterns observed under STEPS. The range remains wide: from 5-24 GJ/household in Tsévié to 10-80 GJ/household in Yaoundé.

The distributional impacts of the alternative scenarios, as measured by Gini coefficients for energy use and GHG emissions, reveal complex and sometimes counterintuitive patterns across the studied cities. Figure 63 above illustrates these patterns through spider diagrams, where proximity to the centre indicates *lower* inequality (smaller Gini coefficient). The Blues scenario shows significant but heterogeneous impacts on energy use inequalities. In cities like Cape Town and Kasese, the scenario achieves substantial reductions in energy use inequality compared to the baseline, with Kasese's Gini coefficient dropping markedly from 0.32 under STEPS to 0.08. However, some cities experience slight increases in energy use inequality - Dakar's coefficient rises from 0.15 to 0.18, while Nairobi's increases from 0.20 to 0.27. The Blues scenario's impact on emissions inequality is more consistently positive relative to the baseline, with notable reductions in Dakar (0.29 to 0.13), Cape Town (0.23 to 0.15), and Tsévié (0.41 to 0.24).

Harmony, despite its ambitious clean energy targets, demonstrates limited effectiveness in reducing inequalities. In several cases, it actually exacerbates disparities. For example, Kasese's energy use Gini coefficient increases from 0.32 under STEPS to 0.37 under Harmony. This counterintuitive result stems from the scenario's approach to fuel switching - particularly its emphasis on LPG as a transition fuel. The complete phase-out of biomass (from 74% in STEPS to 0%) coupled with differential adoption rates of modern fuels across income groups appears to widen rather than narrow energy use disparities. The emissions impact under Harmony is similarly mixed, with some cities like Cape Town seeing increased emissions inequality (Gini coefficient rising from 0.23 to 0.43).

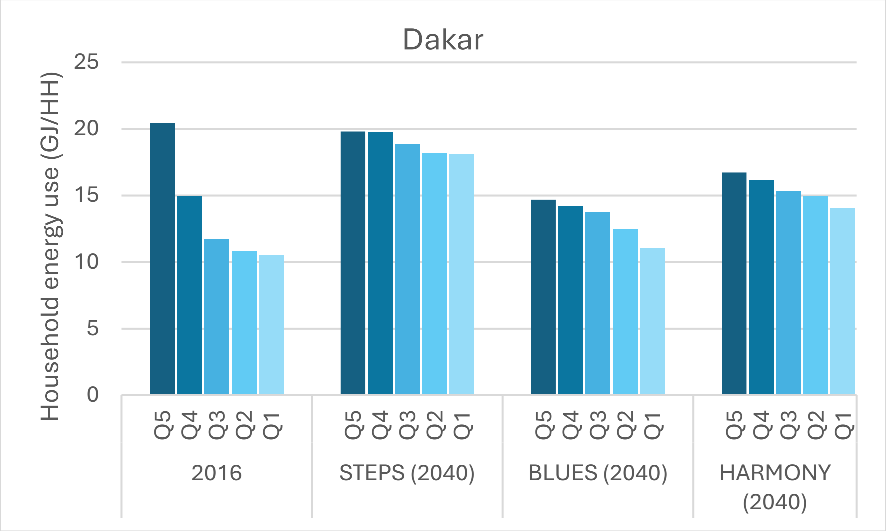
Overall, while STEPS provides a great starting point for reducing inequalities, more ambitious targets, through a community-led, bottom-up approach as modelled in the Blues scenario, can yield substantially better equity outcomes, though the patterns are complex.

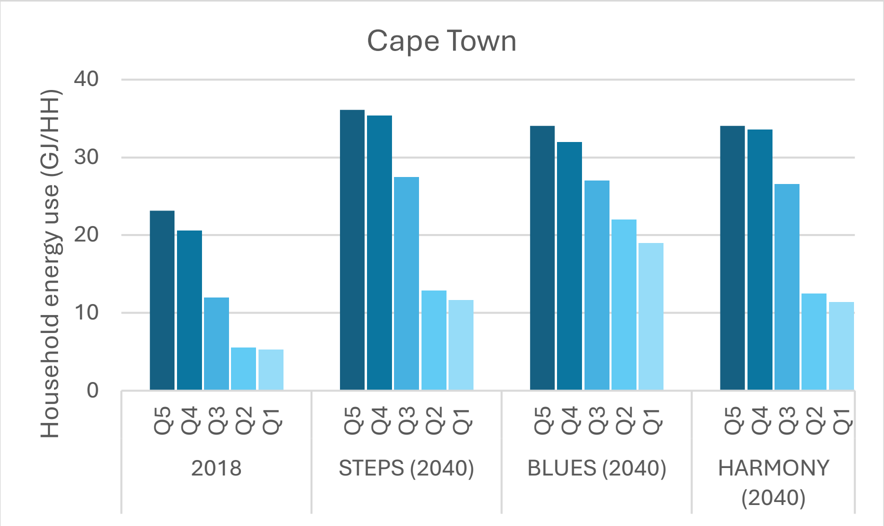
Another key finding from the analysis is that incremental gains in clean energy access, as measured by the level of access and use of electricity and LPG, do not always translate to an equivalent reduction in inequality points, as measured by the Gini coefficients. In other words, the model results suggest that clean energy access does not sufficiently demonstrate a linear relationship with inequality reduction. In Tsévié for example, while the share of clean energy in the household energy mix increased dramatically from 13% in the STEPS scenario to 100% in the Blues scenario by 2040, the Gini coefficient of household energy use only decreased by 16%. This non-linearity may be attributed to:

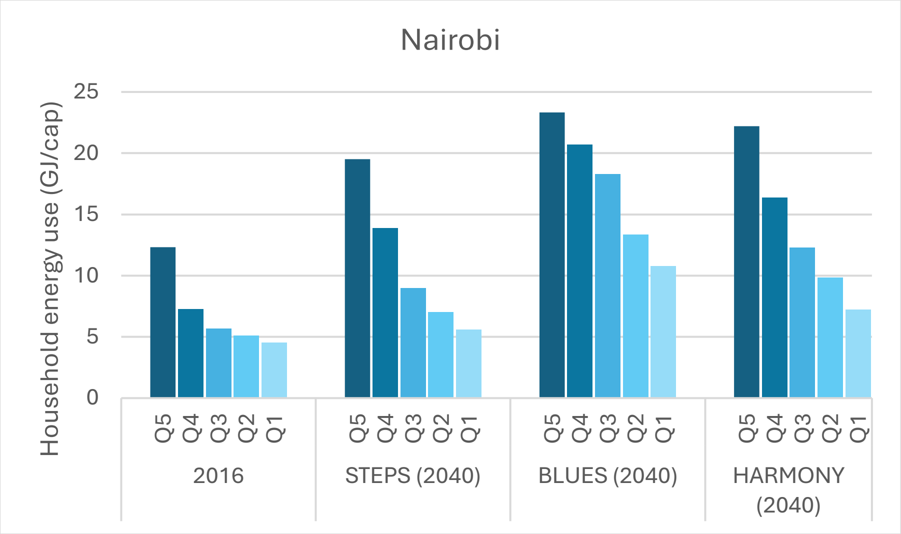
1. Differential adoption rates: While overall clean energy access increases, higher-income households often adopt modern energy services more rapidly and comprehensively. This is evident in the household energy use ratio between Q5 and Q1, which remains high or even increases in some cities under Harmony.
2. Energy service levels: As households gain access to modern energy, higher-income groups tend to expand their energy services more extensively. For instance, in Kasese, despite achieving 100% clean energy access under Blues, the absolute consumption differences between quintiles remain significant.

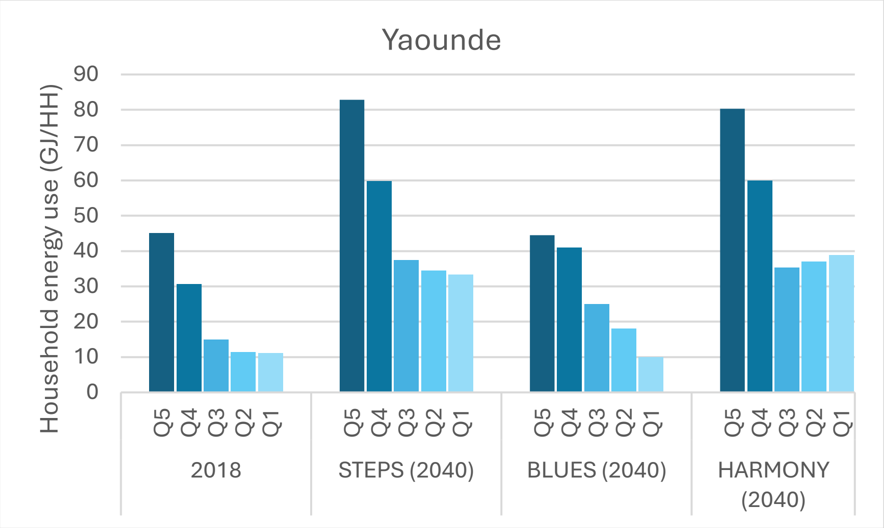
While the model results might not provide a conclusive argument for this finding, it nonetheless suggests a threshold beyond which further increases in decarbonization targets may not significantly advance equity goals, although in absolute terms higher ambition levels in most cases result in net positive impacts on equity metrics.

The temporal evolution of these inequalities, shown in Figure 65 and Figure 66, reveals transitional challenges in the energy transition process. The observed 'bumpy rides' - particularly evident in Kasese (2030-2035) - illustrate how asynchronous adoption of clean energy technologies across income groups can temporarily exacerbate inequalities. These periods typically occur when lower-income households lag in the transition, temporarily bearing a disproportionate share of traditional fuel use and its associated emissions before catching up.


Dakar
Household energy use (GJ/HH)
25
20
15
10
5
0
Q5 Q4 Q3 Q2 Q1
2016
STEPS (2040)
BLUES (2040)
HARMONY (2040)


Cape Town
Household energy use (GJ/HH)
40
30
20
10
0
Q5 Q4 Q3 Q2 Q1
2018
STEPS (2040)
BLUES (2040)
HARMONY (2040)


Nairobi
Household energy use (GJ/cap)
25
20
15
10
5
0
Q5 Q4 Q3 Q2 Q1
2016
STEPS (2040)
BLUES (2040)
HARMONY (2040)


Yaounde
Household energy use (GJ/HH)
90
80
70
60
50
40
30
20
10
0
Q5 Q4 Q3 Q2 Q1
2018
STEPS (2040)
BLUES (2040)
HARMONY (2040)

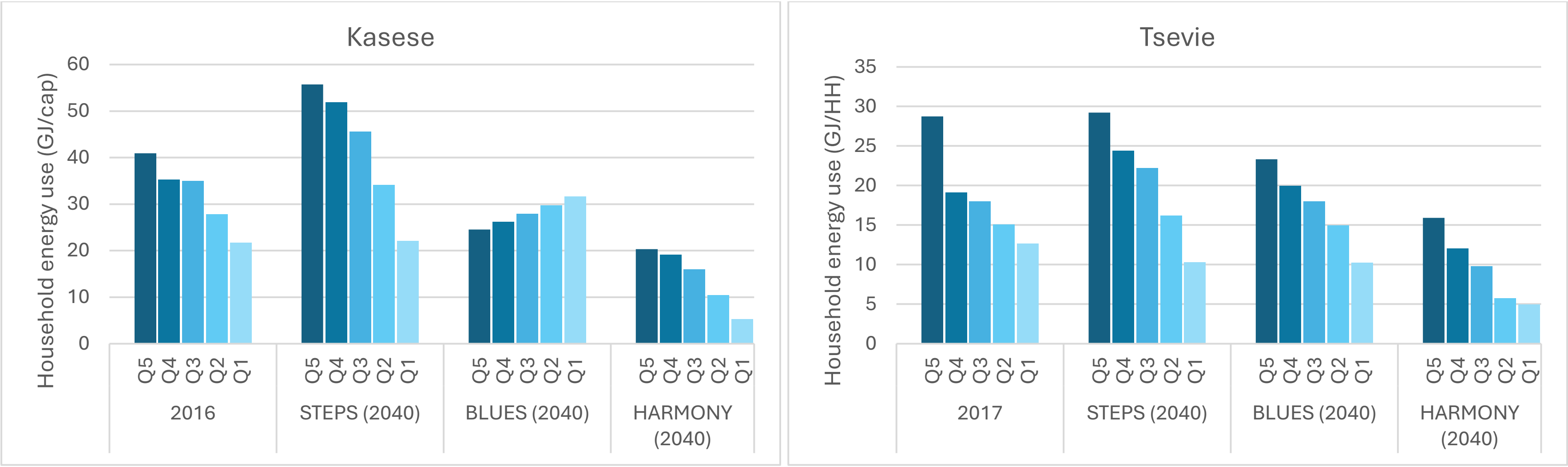
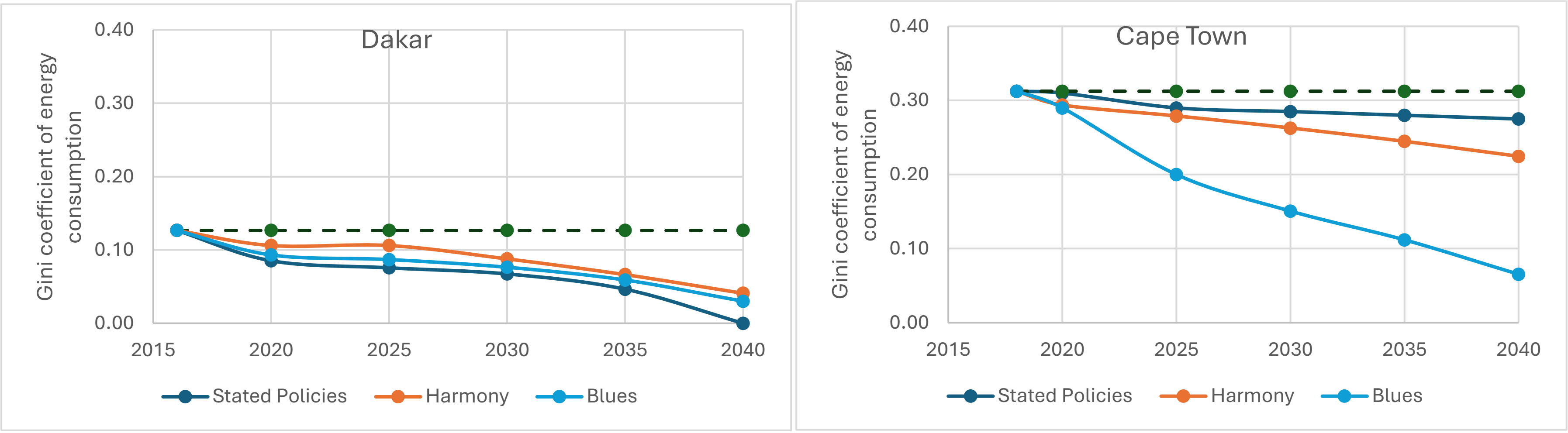


Figure 64 Per capita household energy use by income quintile across all scenarios in all six cities, 2040.



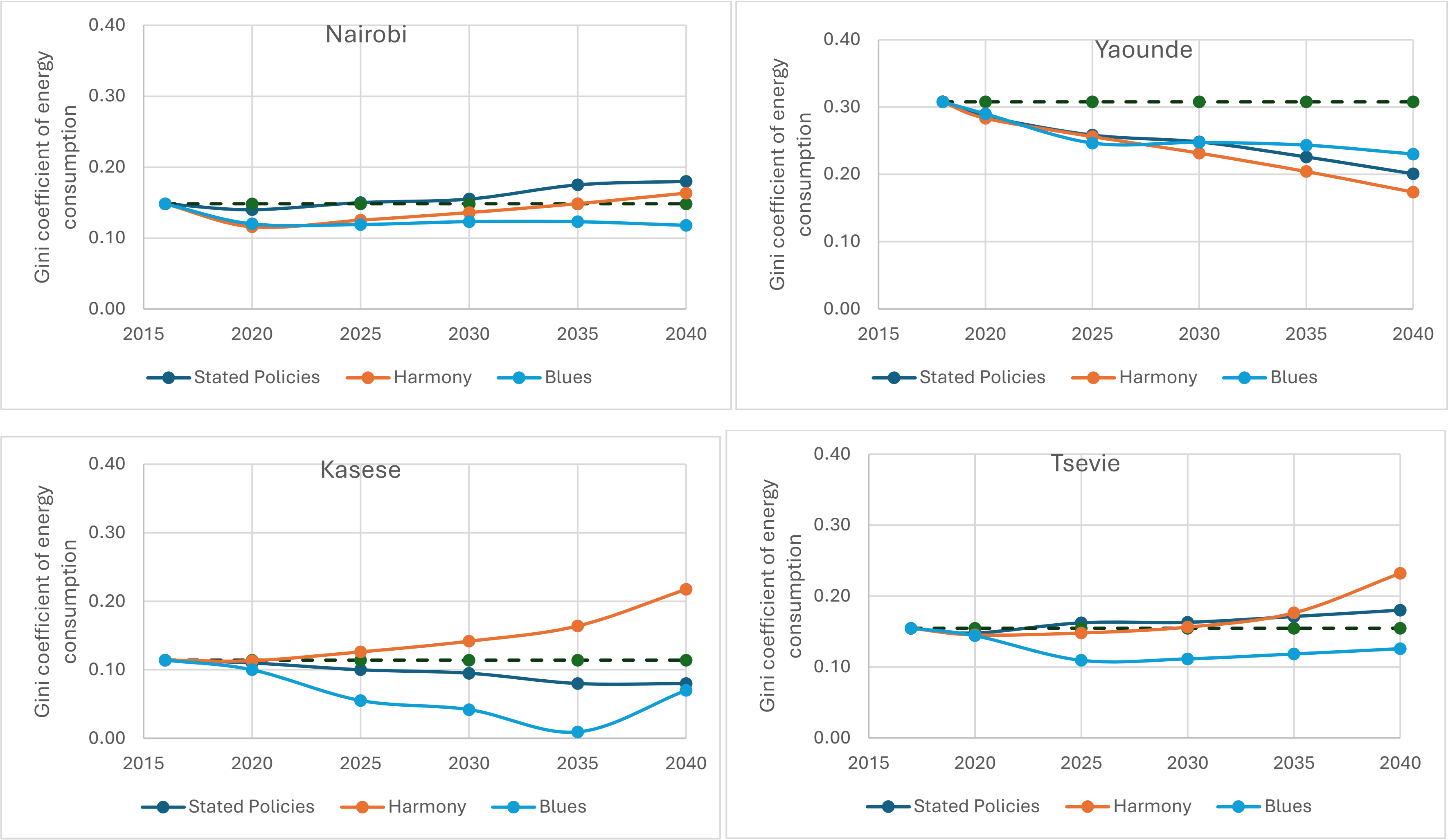
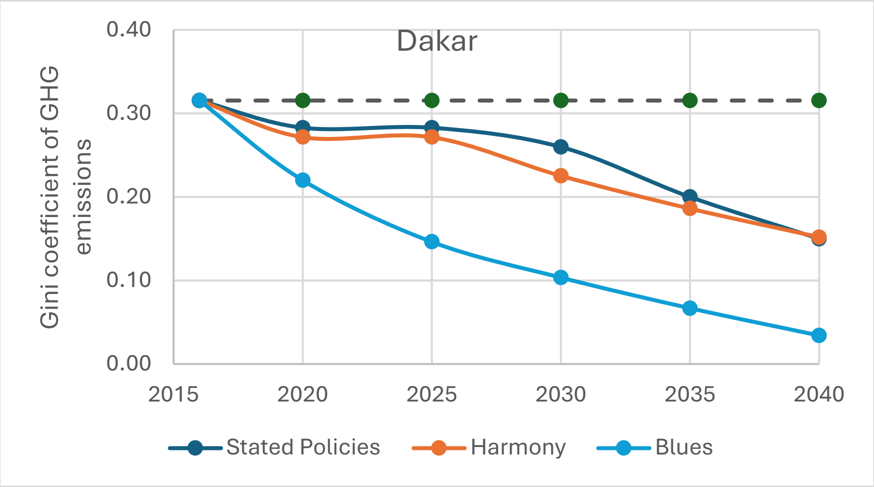
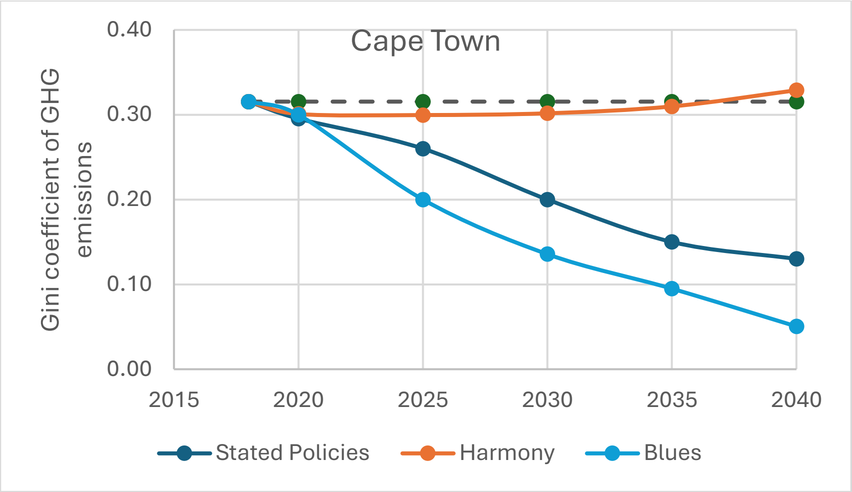
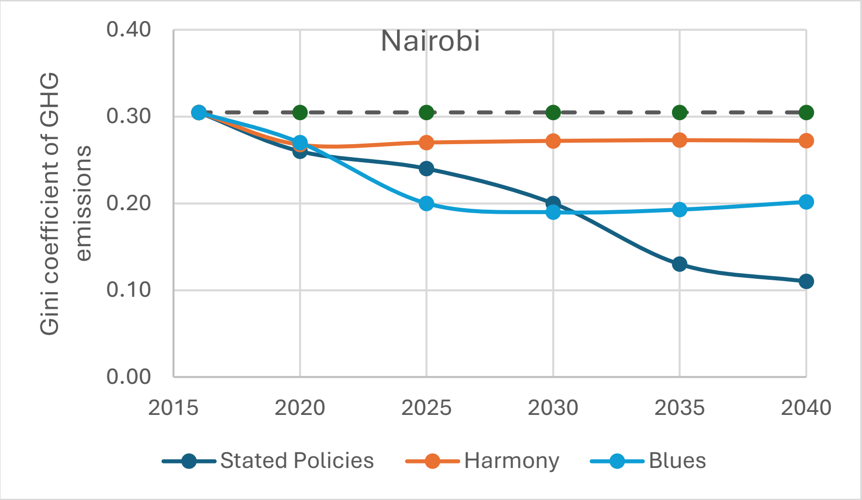
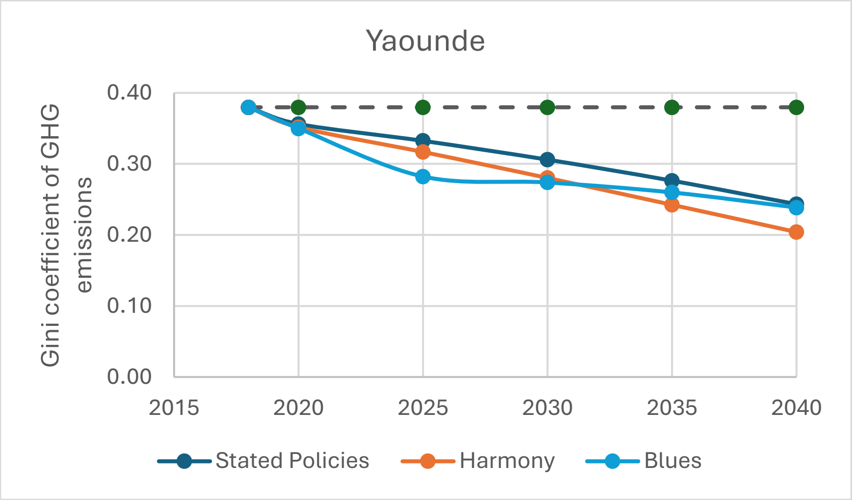


Figure 65. Gini projections of household energy use across all modelled scenarios for all six cities.
All Gini coefficients are calculated using useful energy.


Dakar
Gini coefficient of GHG emissions
0.40
0.30
0.20
0.10
0.00
2015
2020
2025
2030
2035
2040
Stated Policies
Harmony
Blues


Cape Town
Gini coefficient of GHG emissions
0.40
0.30
0.20
0.10
0.00
2015
2020
2025
2030
2035
2040
Stated Policies
Harmony
Blues


Nairobi
Gini coefficient of GHG emissions
0.40
0.30
0.20
0.10
0.00
2015
2020
2025
2030
2035
2040
Stated Policies
Harmony
Blues


Yaounde
Gini coefficient of GHG emissions
0.40
0.30
0.20
0.10
0.00
2015
2020
2025
2030
2035
2040
Stated Policies
Harmony
Blues

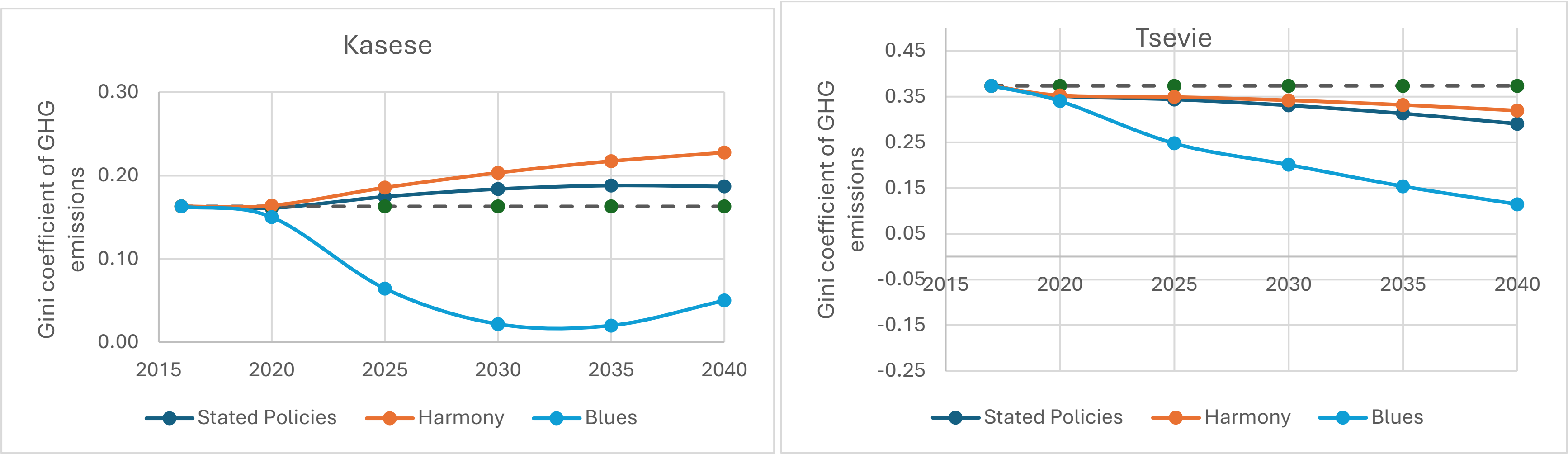


Figure 66. Gini projections of household GHG emissions across all modelled scenarios for all six cities.
All Gini coefficients are calculated using useful energy.

6.3. Impact of Income redistribution on inequalities

While previous sections examined how energy-focused policies and measures in STEPS, Blues, and Harmony scenarios affect energy and GHG emissions inequalities, this sub-section presents a different approach exploring how vertical income redistribution policies (IR PAMs) might influence household energy patterns. Such policies could include mechanisms like cash transfers, social grants, universal basic income, tariffs, aimed at promoting economic stability and reducing inequalities. This complementary analysis aims to understand whether addressing income inequality directly could offer additional insights for just urban energy transition planning.

6.3.1. Method

The analysis follows a straightforward three-step process:

1. **Income Adjustment**: First, since the current structure and capabilities of the UHEM model do not support the direct implementation of these IR PAMs – analysis of these PAMs require more advanced economic modelling – we simulate income redistribution by adjusting household income levels across quintiles. Specifically, we reduce Q5 (highest quintile) income by 30-50% and redistribute this amount to lower quintiles (Q1-Q3). As shown in Table 15, this results in significant changes - for example, in Cape Town, Q1 income increases from $4,484 to $19,717, while Q5 income decreases from $222,847 to $178,278.

2. **Model Recalculation**: Using these adjusted income levels, we recalculate household energy parameters using the same UHEM model equations 8-13 presented in Chapter 3. These equations, which relate household income to energy use patterns, remain unchanged – only the income inputs to the UHEM model are modified. This maintains methodological consistency while isolating the effect of income changes.

   For example, rerunning the modelled equation of electrification (equation 9, section 3.6.2) using the adjusted income figures in Table 15, we calculate that 19.2% of Q1 households in Tsévié would become electrified, compared to the modelled base year of 4.6%. Concurrently, 51.6% of these households will now gain access to small electrical appliances, based on equation 13, as opposed to the 38% in the base year. While this section broadly focuses on the inequalities, detailed numerical results on the changes in energy use and activity data, based on the new disposable incomes, are provided in the online SI file.

3. **Comparative Analysis**: Finally, we compare the resulting energy use and emissions patterns with those from STEPS, Blues, and Harmony scenarios.

	Dakar	Cape Town	Nairobi	Yaoundé	Kasese	Tsévié
Q1 actual	6 492	4 484	3 448	4 463	2 039	1 906
Q1 adjusted	11 755	19 717	7 993	10 597	5 951	4 796
Q2 actual	12 603	8 489	7 236	9 817	6 593	6 105
Q2 adjusted	17 373	23 443	11 495	15 546	10 162	8 667
Q3 actual	18 031	16 682	11 342	16 080	9 702	9 105

Q3 adjusted	22 365	31 064	15 292	21 335	13 037	11 432
Q4 actual	24 919	34 702	18 126	25 054	14 713	26 966
Q4 adjusted	24 919	34 702	18 126	25 054	14 713	26 966
Q5 actual	71 837	222 847	63 764	85 587	54 079	38 897
Q5 adjusted	57 470	178 278	51 011	68 470	43 264	31 117

Table 15. Actual and adjusted mean household incomes by income quintile in Constant 2011 US Dollars.

It is however important to note some limitations of this approach. First, the analysis assumes successful implementation of income redistribution policies. Secondly, it maintains existing relationships between income and energy use, which might change under actual income redistribution; and thirdly the model doesn't capture potential structural changes in energy markets that might result from large-scale income redistribution.

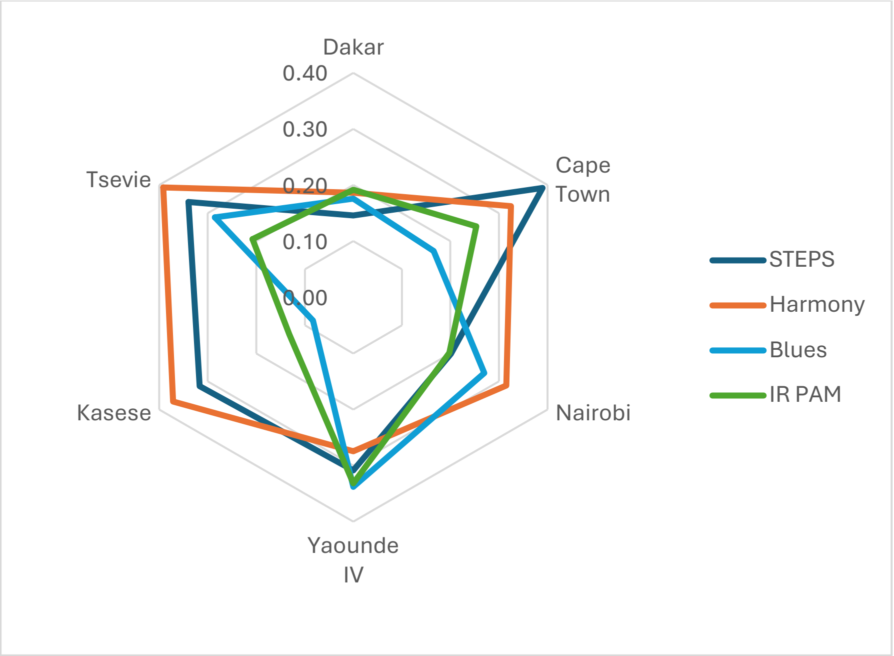
6.3.2. Results

Figure 67 is a reworked version of Figure 63 showing the impact of these IR PAMs (green line) on the Gini coefficient of household energy use and GHG emissions versus STEPS, Blues and Harmony, where proximity to the centre indicates *lower* inequality (smaller Gini coefficient).

A key strength of IR PAMs is their consistency in reducing inequalities across all studied cities relative to the base year, contrasting with the more variable outcomes observed under STEPS, Blues, and Harmony scenarios. Compared with Harmony (orange line), IR PAMs outperform in four of the six cities, suggesting that direct income redistribution may provide a more potent lever for mitigating energy inequalities than top-down, municipally driven approaches. However, their edge over the Blues scenario is more limited, achieving better outcomes only in Nairobi and Kasese, where they reduce Gini coefficients of energy use by 18% and 5% respectively. Taken together, these findings imply that while IR PAMs alone may not fully resolve existing disparities in urban energy systems, they can play a vital complementary role alongside energy-focused PAMs to foster more equitable outcomes.

While increased income leads to higher energy consumption across all household quintiles, the analysis reveals a non-linear response. Lower-income households (Q1 and Q2) show proportionally larger increases in energy consumption compared to higher-income households (Q3 and above). This differential response suggests that income redistribution could be particularly effective at addressing energy poverty among the most vulnerable households.

Perhaps most significantly, the analysis reveals that the relationship between reduced income inequality and energy inequality is not straightforward. This non-linearity is exemplified in the contrasting cases of Dakar and Cape Town. In Dakar, a 43% reduction in income Gini coefficient translates to a smaller 29% reduction in energy use Gini coefficient compared to the base year. Conversely, Cape Town experiences a larger 43% reduction in energy use Gini coefficient from a smaller 31% reduction in income inequality. Similar non-linear patterns emerge in the relationship between income redistribution and GHG emissions inequalities.



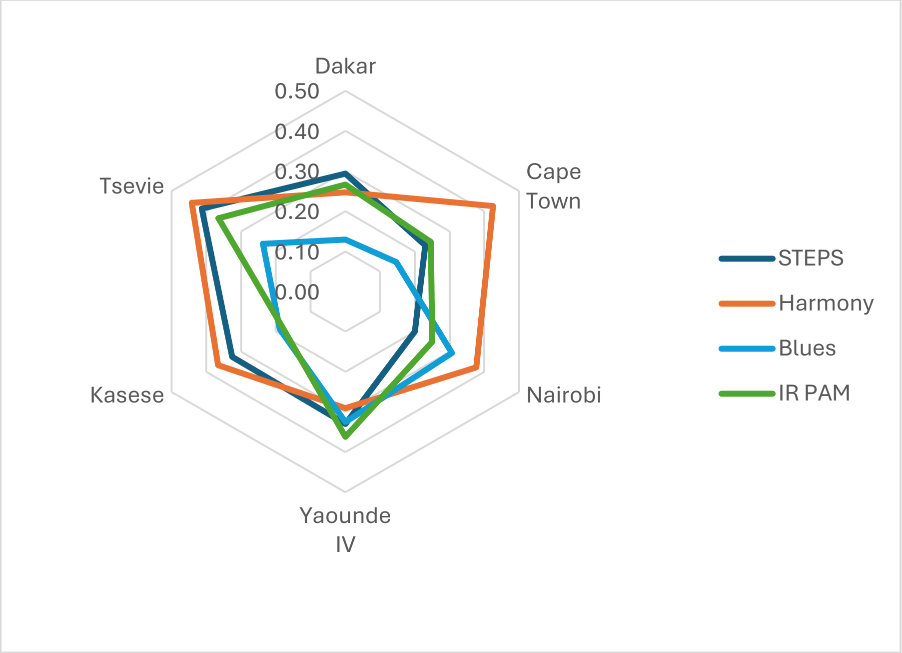


Figure 67. Comparative analysis of the effect IR PAMs on the Gini coefficient of household energy use (upper panel) and Gini coefficient of household GHG emissions (lower panel) in 2040.
(0 = Perfect equality, 1 = Maximal inequality). All Gini coefficients are calculated using useful energy.

6.4. Summary of findings of chapter 6

This chapter has explored alternative pathways to achieving just energy transitions in six African cities by developing and analysing two scenarios - Blues and Harmony - designed to address the equity limitations identified in current policy commitments (STEPS). Through quantitative modelling using the earlier-developed UHEM model, the analysis reveals several important findings about the relationship between different approaches to energy transition and their impacts on household energy inequalities.

First, both policy scenarios achieve significant progress in clean energy access, though through distinctly different mechanisms. Blues, with its bottom-up approach, achieves complete electrification of household energy demand across all cities, driving substantial increases in electricity consumption (4,900-5,800 kWh per household) that exceed decent living standards. Harmony, through its top-down municipal-led approach, makes more modest but structured progress, particularly in smaller cities where electricity's share increases significantly (from ~12% under STEPS to 47% under Harmony), with remaining demand met by LPG.

Second, the scenarios demonstrate that increased clean energy access does not guarantee reduced inequalities in energy use. Blues shows mixed results in reducing energy use inequalities - achieving substantial reductions in some cities (Kasese's Gini coefficient dropping from 0.32 to 0.08) while slightly increasing inequalities in others (Dakar rising from 0.15 to 0.18). Harmony, despite ambitious clean energy targets, sometimes exacerbates inequalities due to differential adoption rates of modern fuels across income groups.

Third, the analysis reveals important spatial and temporal patterns in energy transition impacts. Smaller cities show the most dramatic improvements in electricity access and consumption, with increases of up to 1000% in some cases, far outpacing changes in larger cities. However, the transition path is not smooth, with 'bumpy rides' during periods when lower-income households temporarily lag in adoption of clean energy technologies.

The experimental analysis of income redistribution policies (IR PAMs) provides complementary insights, suggesting that direct income PAMs might offer more consistent inequality reductions than energy-focused PAMs alone. However, their modest performance compared to the Blues scenario suggests they should be viewed as complementary rather than substituting for ambitious, community-driven energy transition PAMs. Also, the non-linear relationship between income and energy inequalities indicates that comprehensive approaches combining both income and energy interventions might be necessary.

Moving beyond the empirical results presented in this chapter, Chapter 7 synthesizes these findings within the broader context of urban energy planning, providing actionable insights and policy implications for policymakers seeking to design and implement more equitable energy transitions in African cities.

Chapter 7 : Discussion and Policy Implications

This chapter synthesizes and discusses the key findings from the modelling and analysis presented in Chapters 4, 5, and 6, examining their implications for urban energy transitions in Sub-Saharan Africa. The discussion extends beyond the analytical results to critically evaluate how these findings contribute to our understanding of energy and emissions inequality at the city level. By connecting the analytical outcomes to broader theoretical frameworks and existing literature on just energy transitions, this chapter develops insights relevant for both academic discourse and policy formulation. The chapter then derives policy implications and practical recommendations to support decision-makers in implementing more equitable urban energy transitions. Finally, the chapter concludes by presenting the limitations of the research in this thesis, which readers should bear in mind in interpretating of the results.

In doing so, Chapter 7 therefore brings together insights gleaned from all four research sub-questions, providing a unified perspective on the research objectives. This integrated discussion allows us to draw broader conclusions about the challenges and opportunities for achieving equitable urban energy transitions in African contexts.

7.1. Discussion

The discussion in this section examines ten key findings that emerged from the analysis in previous chapters. Each finding in section 7.1.1 and 7.1.10 draws on evidence from previous chapters, connecting analytical results to theoretical frameworks and existing literature to inform policy and research directions across diverse SSA urban contexts.

7.1.1. Heterogeneity in urban energy profiles and context-sensitive approaches

Section 4.2 provides a detailed understanding of the heterogeneity in the base year energy profiles of the six case study cities, demonstrating that urban energy transitions must account for diverse starting points.

This heterogeneity manifests across multiple dimensions, with each city presenting distinct characteristics and challenges. For example, Tsévié not only records the lowest per capita electricity usage in the base year (Figure 19) but also exhibits the most significant disparities in household electricity consumption, highlighting a substantial gap between the most and least energy-consuming households (Figure 31). Conversely, Cape Town, while having the most unequal distribution of household energy use across its income quintiles in the base year (Figure 22), boasts one the most energy-efficient economy among the case studies (Figure 19) when energy use is measured per unit of GDP ($million). These contrasts, detailed in Sections 4.1 and 4.2, highlight the complexity of urban energy systems and the need for nuanced understanding of local contexts.

Beyond consumption patterns, the cities also differ markedly in their structural characteristics. As presented in Section 3.1, these differences encompass infrastructure development levels, urban morphology, resource endowments, access to investment capital, and institutional capacity. These base year conditions influence not only the effectiveness of energy transition interventions but also shape potential pathways for reducing energy and emissions inequality.

The analysis raises important questions about the focus of urban energy transition efforts: Should they emphasize scaling up agricultural output or service-sector activities? Is transitioning to clean cooking more urgent than prioritizing efficient appliances? Which inequality metrics should guide decision-making to address the urban energy divide effectively?

The findings from Chapter 4 therefore challenge the notion of one-size-fits-all approaches to urban energy policy design, as commonly applied in current city focused programmes and highlights the importance of context-specific policies that consider local nuances and needs. It also suggests that the implementation of national-focused energy transition plans may not necessarily result in uniform impacts across all urban jurisdictions, unless the city-level requirements for the energy transition are well understood. However, a critical limitation in current practice emerges from the widespread use of data and models developed for different contexts. Climate action plans for SSA cities often rely on proxies from developed economies, potentially misrepresenting local dynamics. This limitation is compounded by the predominance of non-African organizations in strategy development (Mutiso *et al.*, 2022), further distancing planning from local realities.

Clearly, a knowledge of the local urban context, and the starting point of each city, is necessary to guide the implementation of national policies, and this requires several key elements. First, they must be built on granular local data collection and analysis, moving beyond generalized assumptions. Second, they necessitate the development of local research expertise such that the exercise objectives are not compromised. Finally, effective urban energy policies, particularly those seeking fair and equitable outcomes, must be co-designed through participatory processes and collective wealth building, to meet the local needs.

7.1.2. Transformations required to bridge the energy services gap

The analysis reveals a substantial disparity between current energy consumption levels and the minimum requirements for decent living across the studied cities. Chapter 5's comparative analysis (Section 5.3) demonstrates that this gap necessitates transformational rather than incremental changes across multiple dimensions of urban energy systems.

The most striking evidence of this gap emerges in the context of meeting the Modern Energy Minimum (MEM) target of 1000 kWh per person annually. As shown in Figure 20, achieving this benchmark would require significant expansion of urban energy systems - from a 44% increase in Nairobi to an extraordinary 9000% increase in Kasese. This finding aligns with the inequality analysis in section 4.2, which reveals that base year energy consumption inequalities across the six cities are generally quite high, posing a challenge in supporting basic services across all income quintiles, particularly in smaller cities.

The scale of transformation required extends beyond mere quantity of energy supplied. The analysis in 4.1.2 shows that electricity comprises only 3-30% of total final energy demand across the studied cities, significantly below the levels needed for modern energy services. This limited electrification presents both a challenge and an opportunity in the context of global trends toward comprehensive electrification. The modelled scenarios in Chapter 6 demonstrate how this 'electricity everything' paradigm, in the Blues scenario, could expand access to energy services, particularly in reducing energy inequality.

Energy demand patterns for productive uses (i.e. across the commercial, industrial and agricultural sectors) provide further evidence of the transformation required. The sectoral analysis in Section 4.2.3 reveals consistently low shares of productive use in final energy demand, indicating limited economic diversification and industrialization. This is particularly significant given the established correlation between productive use of energy and economic development as demonstrated in the literature (Rockefeller Foundation, 2024).

These findings align with and extend recent literature on power system transformation in Africa (Pappis *et al.*, 2019; IEA, 2022b; Nana and Dioha, 2024). The thesis' city-level analysis provides more evidence of the scale of transformation required at the urban level, with the scenarios modelled in Chapter 5 and Chapter 6 demonstrating that achieving these transformations will require a combination of the central grid and decentralized technologies, improved regulatory frameworks and new approaches to governance. However, many of these necessary transformations fall outside municipal jurisdiction, as detailed in section 2.3.

The magnitude of transformation required presents both challenges and opportunities and will require innovative institutional arrangements and financing mechanisms. Further, the expansion of urban energy systems multiple fold will require very large investments in infrastructure and therefore innovative finance approaches such that the burden of these urban energy transitions is not placed on the funds available from public sources.

7.1.3. Patterns of household energy use and income inequality

Analysis of household energy consumption patterns reveals a notable asymmetry between energy use and income distributions. While both exhibit significant heterogeneity across the studied cities (reported in section 4.1), energy consumption inequalities consistently demonstrate lower magnitudes than income inequalities. The quantitative analysis demonstrates three key hierarchical relationships in inequality measures:

1. Income inequality shows the highest magnitude across all cities
2. GHG emissions inequality follows as the second most pronounced
3. Energy consumption inequality exhibits the lowest levels, sometimes up to half that of income inequality (e.g. Dakar and Kasese – see Figure 22).

This hierarchy persists across all six cities despite their varying economic and social contexts, suggesting a fundamental relationship between these variables. This observation is consistent with similar studies on the nexus between energy use and income inequality at the subnational level (Khan and Heinecker, 2018; Bardazzi, Bortolotti and Pazienza, 2021). However, it presents an interesting contrast to Pachauri (2014) country-level analysis, which found that disparities in energy access and use, both within and across countries, often mirror or even exceed income inequalities when assessing a wider set of economic sectors.

The theoretical framework developed in 2.6 helps explain these patterns. Energy's status as a fundamental need creates a "floor effect" in consumption patterns - households prioritize basic energy services even under severe income constraints. This necessity-driven consumption pattern results in more equitable distribution of energy use compared to income, which faces no such constraints. The analysis in Chapter 4 provides evidence for this theoretical expectation, showing how even the lowest income quintiles maintain decent energy consumption levels despite at times severe income limitations.

While the lower magnitude of energy inequality might suggest it as an easier target for policy intervention, our scenario analysis in Chapter 6, as will be explained in subsequent sections, indicate that addressing income disparities might at times offer a more effective leverage for reducing inequalities.

7.1.4. Inequality patterns in electricity use

Among all the fuels examined in this study, electricity consumption uniquely shows a near-linear relationship with GDP per capita (consider for instance Figure 20). Generally, the higher the GDP, the higher the average electricity consumption of that city, an observation finding that aligns with existing literature that highlights the central role of electricity as a precursor for socioeconomic development in the modern era (Farquharson, Jaramillo and Samaras, 2018; Blimpo and Cosgrove-Davies, 2019).

Also, among the various energy carriers examined, electricity consistently emerges as one of the most unevenly used resources across the six cities in their base years, with Gini coefficients ranging from 0.34 in Kasese to 0.63 in Tsevié. Notably, these Gini coefficients for electricity consistently surpass those of total energy consumption and, in some instances, even exceed the measured inequalities in household income. Moreover, the study finds that high electricity access does not necessarily equate to equitable utilization, as evidenced by Dakar, Cape Town and Yaoundé, where electricity use Gini coefficients of energy use are among the highest i.e. 0.55, 0.45 and 0.55 respectively. Similar findings in Colombia and China also showed significant nationwide inequalities in electricity consumption, with Gini coefficients often higher than 0.5 (Dong and Hao, 2018; Cabello Eras *et al.*, 2022).

The non-correlation of electricity consumption distribution with grid access is particularly strong in Sub Saharan Africa, with millions of urban residents living in proximity to the electricity grid, despite receiving unreliable or inadequate power or having no access at all (Tenenbaum, Greacen and Shrestha, 2024). Adding to this, traditional approaches to electricity access in Africa have often stubbornly focused on the deployment of solar home kits, which have been heavily criticized for only providing marginal access to electricity, mainly for lighting, without further empowerment toward economic growth (Kojima *et al.*, 2016; Munro, van der Horst and Healy, 2017). As Mutiso (2019) aptly states, "it’s not just about lights for every home, it’s [about] power for African cities that are growing fast."

Electricity access and use inequalities find a reflection in income inequalities, gender inequalities and inequalities in other developmental dimensions (Pachauri and Spreng, 2012). These inequalities limit productive opportunities, economic growth, and employment, and negatively impact human health and welfare due to exposure to emissions from the use of inefficient solid fuels.

Beyond focused efforts on improving electricity access, a more holistic approach is required to promote its equitable use. This should combine policy and technological innovations, with efforts to improve affordability and reliability, ensuring that low-income households can truly benefit from increased access.

7.1.5. Influences of urban scale in policy implementation

The status quo analysis in section 4.1 reveals a systematic relationship between city size and energy system characteristics, with larger urban economies demonstrating both higher efficiency and cleaner energy profiles. Analysis of energy intensity (energy use per GDP) across the studied cities shows that the three largest urban economies - Cape Town, Nairobi, and Dakar - consistently demonstrate higher efficiency levels compared to smaller cities, as evidenced by their positioning below the correlation line in Figure 19. This is largely in alignment with existing literature and primarily driven by technological advancements (Lee and Chang, 2007; Ang and Goh, 2018). Several studies have shown that this ratio takes on an inverse U-shape with increasing GDP, increasing in the early phase of economic development as energy-intensive industries are introduced, reaching a peak and then decreasing as development progresses and structural shifts in production occur (Ang, 2006; Ang and Goh, 2018).

Another noteworthy observation is that larger quantities of energy use often translate to higher shares of cleaner fuels both across and within cities. For instance, in the respective base years, the share of electricity in the total final energy demand ranges from 16-30% in Dakar, Yaoundé, Cape Town, and Nairobi but only 2-3% in the smaller towns of Tsévié and Kasese (Figure 21). Within the cities themselves, significant disparities in clean energy access are evident among income quintiles. In Dakar for example, electricity constitutes 20% of Q5’s final energy demand versus 1% for Q1 (Figure 30). Perhaps even more striking is the finding that clean fuels (electricity and LPG) and backup power sources show even greater inequality than income distribution itself (Figure 31).

These patterns have implications for energy services, as demonstrated in Section 4.2.1.2. Activities dependent on clean fuels, particularly home appliance use and lighting, exhibit the highest levels of inequality. These disparities are primarily driven by income differences, creating a self-reinforcing cycle between economic and energy inequality (Figure 31).

Other studies have equally found a positive correlation between lack of access to clean energy and a worsening global income inequality (Uzar, 2020; Acheampong, Dzator and Shahbaz, 2021), offering policymakers the opportunity to reduce income inequality and environmental degradation at the same time.

Inequitable access to renewable energy technologies have also risen to the table amidst growing debates on the need for equitable outcomes of the energy transitions (Brockway, Conde and Callaway, 2021; McNamara *et al.*, 2022). For example, it is common knowledge that the early adopters of distributed energy resources (DERs) are generally the most affluent households and businesses who can afford the high upfront cost of this technology. Where financial incentives are in place, these have generally been unequally allocated. In Nairobi and Cape Town for example where penetration of rooftop solar have seen a steep rise in recent years, municipal officials have often reported that over 70% of residential installations were located in affluent suburbs.

Further, several studies have also highlighted that the perpetration of current utility pricing approaches in the face of increasing penetration of renewables, particularly DERs, have introduced perverse cross-subsidisation or cost-shifting, as utilities see reduced payment from these customers (Athawale and Felder, 2016; Ansarin *et al.*, 2022). This adds a new layer to the inequality debate from a tariff angle, suggesting an emphasis on tariff setting for DERs to ensure that rates continue to protect affordable access to electricity and encourage the efficient use of renewable resources while minimizing unnecessary cross-subsidization between customers.

City size also inversely correlates with policy impact magnitude**.** The scenario analysis in Chapter 6 shows that the effectiveness of energy transition scenarios, particularly blues and STEPS, demonstrates an inverse relationship with city size, with smaller cities and lower-income households showing dramatically larger responses to interventions. This finding provides important insights for policy targeting and implementation strategies.

For example, in the income redistributive PAM analysis in section 6.3, we observed that as income rises, all households consume more energy, but the rate of increase for households up the income ladder (e.g. Q3) is lower than for lower-income households (Q1 and Q2). It is well document that low-income households face high energy burdens and low energy affordability (Marilyn A. Brown *et al.*, 2020; Marilyn A Brown *et al.*, 2020). These results therefore suggest that when they receive an additional unit of income, a larger portion of it is allocated to energy consumption compared to higher-income households.

Similar observations are equally made at the city level, with the smaller towns generally experiencing a bigger multiplier effect, both in terms of improved access and use. For instance, Kasese and Tsévié experience a near fourfold increase in average household electricity use in the STEPS scenario and an extraordinary 30-fold increase in the Blues scenario relative to the base year (Figure 41 and Figure 62), compared to much smaller increases in the larger cities.

7.1.6. Equity outcomes of existing policy commitments (STEPS scenario)

Analysis of the Stated Policies Scenario (STEPS) reveals that despite lacking explicit equity objectives, this scenario demonstrates some potential for reducing energy inequalities across the studied cities. The results from Chapter 5 provide quantitative evidence of this effectiveness, while also highlighting important variations in impact across different urban contexts

The quantitative analysis in Section 5.2 demonstrates STEPS reduced inequalities in household energy use between 33% in Nairobi to 48% in Dakar relative to the base year, as measured by the Gini coefficient (Figure 40).

STEPS also drives broader improvements in sustainability metrics. The analysis in Section 6.4 reveals significant increases in clean energy adoption, with average household electricity consumption showing remarkable growth - tripling in Dakar and Tsévié and increasing sixfold in Kasese (Figure 41). These improvements in electricity access and consumption suggest that even policies primarily focused on energy system decarbonization can yield important co-benefits for energy equity.

These findings carry important implications for current policy discussions, particularly as countries across Africa develop just energy transition plans. The experience of Senegal, Kenya, and South Africa in incorporating equity considerations into their transition planning could be informed by these results, suggesting that even conventional energy policies might advance equity goals more effectively than previously assumed.

However, as demonstrated in the analysis of the Blues scenario discussed in section 6.2, municipal authorities could achieve even greater equity outcomes beyond STEPS, premised on more ambitious targets and a different approach to implementation. Also, the practical implementation of STEPS however may pose different degree of challenges to municipal governments as many key interventions in STEPS - especially those related to energy supply and technology deployment - fall under national rather than local jurisdiction. This governance challenge is exacerbated by the limited recognition of local government roles in national energy strategies, even when STEPS-aligned policies are adopted at the national level.

7.1.7. Varied outcomes from clean cooking and electricity access PAMs

Analysis of specific PAMs within the STEPS scenario reveals clean cooking and electricity access as the most influential levers for energy system transformation, though with notably different patterns of impact across cities.

In Dakar for instance, clean cooking reduces household energy use inequalities by as much as 32% relative to the base year, while increasing inequalities by 32% and 33% in Tsévié and Kasese, respectively (Figure 42a). Electricity access interventions, on the other hand, produce more consistent outcomes, reducing household energy use inequalities by 13% in Tsévié and over 23% in Kasese (Figure 42d).

The detailed analysis in section 5.3 shows that both policy interventions result in significant shifts in the household energy mix, particularly by facilitating access to and use of clean fuels among lower-income quintiles. However, this shift does not always result in levelling inequalities in the use of these fuels.

Beyond the measures of inequalities quantified in this study, clean cooking and electricity access interventions are the most consequential in delivering socioeconomic gains and addressing broader development and sustainability metrics. Other impacts of clean cooking include saving lives through reduced indoor air pollution, providing economic freedom through reduced cooking energy costs, and positively impacting the environment by reducing deforestation and environmental degradation (IEA, 2023a). Clean access intervention on the other hand not only facilitates electricity access but also expands the range of energy services available to households, which is crucial for economic empowerment. These interventions also offer additional benefits such as reducing the economic burden associated with high operational costs of backup fuels (ex. Diesel) but also significantly diminishing local air pollution – a common issue in areas heavily reliant on backup generators (Sachiko Graber *et al.*, 2020).

Both clean cooking and electricity access have been extensively researched, though often lacking an urban dimension, particularly in Africa. These initiatives typically fall outside the mandates of local governments in SSA, complicating their implementation.

Another challenge associated with transitioning to clean cooking at the local level is that municipal economies, especially in less urban areas, are heavily biomass-based. Transitioning to electricity will inevitably hurt local businesses and possibly public coffers that depend on this resource. Tsévié and Kasese, for example, might experience negative fiscal impacts on their local economies as cooking becomes electrified, with possibly even much broader economic impacts along the biomass production supply chain. IEA (2023) clean cooking futures modelling also shows that the switch toward clean cooking is expected to reduce the use of firewood and charcoal by 50% globally and 70% in SSA to 2030, with the most precipitous declines in urban areas where most of the charcoal market is today. It equally highlights the need for this shift to be managed responsibly to avoid widespread loss of livelihoods as charcoal and firewood value-chains are a major source of informal employment throughout much of sub-Saharan Africa.

Furthermore, transitioning to electricity for cooking under the current status quo could reinforce the power of monopolies while undermining local businesses. To ensure a fair transition and support local economies, some energy generation functions must be localized.

7.1.8. Blues scenarios effectiveness across multiple metrics

The Blues scenario, which envisions complete electrification of household energy services, demonstrates markedly superior outcomes compared to both STEPS and Harmony scenarios. The analysis in Section 6.2 shows that Blues achieves reductions in household energy use inequality between 16-74% greater than STEPS across Tsévié, Cape Town and Kasese (Figure 63). This improvement in equality metrics is accompanied by dramatic increases in household electricity consumption, ranging from 40% to 950% above STEPS (Figure 62). These substantial gains in both equality and consumption suggest that comprehensive electrification can simultaneously address access and distributional challenges.

The overall net positive impact of electrification in the Blues is yet another reminder of the critical incidence of electricity on energy poverty and inequalities alleviation, as discussed earlier. However, also complimentary to this discussion is that the Harmony scenario reveals that not all approaches to improving clean energy access yield net positive impacts on inequality metrics. In the Harmony scenario, a significantly increased share of LPG use in households, replacing traditional biomass, widens the inequality gap by large amounts in four of the case studies – Dakar, Nairobi, Kasese and Tsévié – relative to STEPS (Figure 63).

This observation raises yet the important question about the effectiveness of nationally or regionally determined policies that may lack visibility into local impacts, such as, recent clean cooking policy recommendations from the IEA (2023) and (IRENA, 2024) for instances, that often generalise the emphasis on LPG, as a transition fuel and a universal solution for meeting household cooking needs.

7.1.9. Effects of clean energy expansion on inequality

The detailed scenario analysis in Section 6.2 shows an important nuance in the relationship between clean energy expansion and equity outcomes, in that the impact of increased clean energy access on inequality reduction demonstrates diminishing returns beyond certain thresholds. For instance, in Tsévié for example, while the share of clean energy in the household energy mix increased dramatically from 13% in the STEPS scenario to 100% in the Blues scenario by 2040, the Gini coefficient of household energy use only decreased by 16% (Figure 62 and Figure 63). Similar findings are discussed in earlier sections regarding the effect of changes in income inequality on energy use inequalities.

Other studies find that there may be a more robust interrelationship between energy justice and renewable energy consumption, when expanding the dimensions of energy inequalities or justice to include ecological parity, economic inclusiveness, and community empowerment (Carley and Konisky, 2020; Sen *et al.*, 2024). This are particularly relevant, as it sheds light on the broader implications of STEPS, Blues and Harmony scenarios beyond the narrowed focus on energy inequalities. Improved clean energy access in these scenarios offer a cleaner environmental profile that helps reduce local pollution, which often disproportionately affects marginalized communities, contributing to improved health outcomes and more equitable environmental landscape. On the other hand, the growth of renewable energy infrastructure from the decentralisation and localisation of generation assets, creates new employment opportunities and stimulates local economic development, especially in areas previously dependent on other forms of energy sources. This economic inclusivity aligns with the principles of energy justice, ensuring that the advantages of transitioning to clean energy are shared broadly.

The biggest challenge, however, sits in the implementation of these scenarios, primarily in financing the roadmap of actions. Although numerous fiscal programmes and instruments exist at the national level across Africa, fiscal decentralisation – whether through transfers from the central government or by granting local governments revenue-raising powers – remains a serious challenge for empowering local governments. Most local governments in Africa depend on national government grants as their main revenue source; they borrow little money (even if they are formally able to) and spend most of their revenue on operations instead of capital investments. This means that they have few funds to invest in new infrastructure projects such as distributed renewable generation. Moreover, factors such as the lack of available income to allocate to energy consumption – as well as the prevalence of several informal settlements that experience poor housing quality, irregular income flows and low demand for electricity – constrain the business case for electrification for utilities. Notably, local governments are constrained in how they can spend public funds (for example, to ensure public finance management best practice, as articulated in South Africa's Municipal Finance Management Act).

Among our case studies, only the City of Cape Town has both the mandate and some degree of fiscal leverage to pull off the mobilization of the colossal capital investments required to finance the transition pathways proposed in the Blues scenario.

7.1.10. Role of income redistributive PAMs in reducing inequalities

Analysis of hypothetical income redistribution policies (IR PAMs) in section 6.3 demonstrate their complementary role to energy-based scenarios (STEPS, Blues and Harmony) in reducing energy inequalities, despite their absence from current local energy strategies. Such policies might include cash transfers, social grants, universal basic income, or income-graduated electricity tariffs, all aimed at promoting economic stability and reducing disparities.

These IR PAMs achieve better in four out of six cities compared to Harmony, while also outperforming Blues in Nairobi and Kasese, where they reduce Gini coefficients of energy use by 18% and 5% respectively (Figure 67). These policies - including cash transfers, social grants, universal basic income, and income-graduated electricity tariffs - show particular promise in addressing energy poverty.

The strong correlation between income inequality and household energy access is well-documented, with numerous studies showing that widening income disparities often exacerbate energy poverty. However, other research highlights that additional dimensions of energy – such as accessibility, reliability, and affordability (Igawa and Managi, 2022) – as well as local governance (Acheampong *et al.*, 2022) and socio-political factors (Certomà *et al.*, 2023), also play significant roles in shaping the relationship between income and energy inequality.

While the analysis IR PAMs analysis is a simplified simulations of the impact of vertical income reallocations, i.e. based on a hypothetical successful implementation of these policies, the findings perhaps underline the key role that income plays in the energy justice or the broader energy transition debate, particularly in driving economic prosperity.

Another noteworthy observation from the IR PAMs analysis is that the impacts of changes in income on energy inequalities are not linear. In Dakar for instance, the income Gini coefficient reduced by 43% which occasioned a 29% reduction in the Gini of household energy use compared to the base year. In Cape Town on the hand, while this experiment led to a 31% reduction in income inequality, the Gini of energy use saw a much sharper decline up to 43% relative to the base year. This highlights once more the need for evidence-based policy implementation, particularly when the policy development is removed from the local context. It is important for policymakers to understand that national or regional policies aimed at addressing income inequalities will have varied impacts on energy poverty alleviation at local level and therefore require granular spatial resolutions to achieve optimal outcomes.

7.2. Policy implications

The previous section discussed ten analytical findings that emerged from this research, the implications for the city and the likely challenges on the road to implementation. This section focuses on implications for policy and a discussion of the key enablers that would enable modelled PAMs to be implemented in reality.

7.2.1. Decentralizing energy governance yields improved equity outcomes through community participation

Based on the analysis in Chapter 6 and later on the discussion in section 7.1, the road to an equitable urban future, as laid out in the Blues scenario, will require nothing short of bold and big steps. Implementing Blues would require a decentralized approach to energy governance, in the form of community-led initiatives and distributed planning, akin to the concepts of energy democracy. Specifically, achieving energy justice through Blues will require placing big bets on bottom-up initiatives such as decentralised electricity access or clean cooking (see sections 5.2 and 6.2), as the opportunities ushered by these are significant towards the realization of a future in which urban residents are lifted out of energy poverty, wealth is built through ownership of generation assets and energy resources are reallocated equitably.

To achieve this large-scale system and societal transformation, municipal governments will first and foremost need an ambitious and perhaps unconventional vision of their role as major players in the deployment and transactive nature of a decentralised energy system.

A. Decentralising electricity access

A key insight from the findings and discussion of both STEPS and blues scenarios (sections 5.2 and 6.2) is that higher access to and increased use of electricity consumption, both at the city and household levels, often correlates with, reduced inequalities, greater efficiencies, enhanced economic welfare, environmental and other associated benefits. The following section outlines key policy, institutional, and regulatory mechanisms that could support the realization of a decentralised access to electricity and municipal level.

1. **Minimising regulatory requirements**: Regulatory hurdles are among the biggest obstacles to achieving a decentralised urban energy system, as in the Blues scenario, where energy becomes the “currency of the future”. For instance, traditional quotas on individual distributed generation installations, like those found in many net metering or billing rules, may constrain the potential of local or community led deployments. Evolving regulatory frameworks could expand citizens participation. For instance, new approaches could enable those with the resources, particularly in urban centres, to install as much solar capacity as the grid can safely absorb. This would then be paired with mechanisms that ensure the benefits of this affordable energy reach less affluent communities.
   Furthermore, the concept of electricity as a common good aligns with the idea of transactive distribution grids, including peer-to-peer energy exchanges (“wheeling”) in contexts like South Africa, where electricity can be transported from generators to remote end-users through existing networks. The study findings on the impact of the Blues scenario highlight the potential value of reducing legal barriers and transaction costs associated with these exchanges to accelerate the provision of clean, affordable energy at scale. This also points to the role of municipalities as possible facilitators in establishing collaborative platforms with national utilities and regulators to build consensus and drive this vision forward.
2. **Integrating distributed energy assets in municipal energy planning**: Current municipal energy transition plans often prioritize utility-scale projects, driven by current wisdom that they are more cost-effective than decentralized alternatives. This is in tandem with the increasing criticism of traditional resource planning tools that until now only optimize the deployment of bulk system resources on the transmission level, with limited visibility into the costs and benefits of the growing number of shared resources on the distribution network.
   As discussed in section 7.1 and also widely supported by a growing literature on this matter, addressing local energy needs while simultaneously considering equity objectives may benefit from integrating distributed energy resources (DERs) more explicitly into both national and local energy planning. Advanced modelling tools that accommodate the growing complexity of modern grids could assist in evaluating DER impacts, including potential cost efficiencies and community-level benefits. Local governments might explore advocating for strategic deployment of rooftop solar and battery storage to meet municipal energy demands, with the bulk system serving the

residual demand. This approach could help maximize the economic and social value of decentralized energy resources.

3. **Reinforcing the distribution grid**: To support the local deployment community-led DERs, especially in urban areas where adoption is highest, it will be important for policymakers in collaboration with local governments to develop comprehensive roadmaps for grid modernization, clearly identifying investment priorities for distribution grid upgrades to facilitate the integration of these resources.
4. **Implementing fair and equitable tariffs:** Rate or tariff setting is an important policy tool for fostering the local deployment of DERs, but it's essential to strike a balance. While well-designed tariffs can incentivize DER adoption, they can also unintentionally shift costs onto non-DER customers, exacerbating existing inequities and diminishing overall social benefits. Supporting a more distributed power system globally, and particularly in urban SSA will require retail tariffs that are unbundled – comprising variable, demand, and fixed charges – and cost-reflective, incorporating temporal and potentially spatial resolutions to capture the true value of DERs.
   Although responsibilities for rate design and regulatory approval commonly lie outside municipal jurisdiction in many contexts (with South Africa being an exception), there are opportunities for municipal authorities, in collaboration with local energy research organizations, to guide further inquiry and advocate for tariff approaches that balance equity with the broader goals of a sustainable urban energy transition.
5. **Metering and billing systems upgrade**: In a decentralised energy system, where transactions from distributed assets are frequent, metering and billing systems will need a significant upgrade. To facilitate seamless transactions, regulatory frameworks could establish new metering specifications and enhance billing systems. These upgrades would ensure accuracy, transparency, and flexibility in energy exchanges, enabling consumers to actively participate and become active voices in the energy transition. Again, Municipal authorities are uniquely positioned to collaborate with local distribution utilities to set up centralised procurement processes for new meters and billing system upgrades to significantly reduce overhead costs and the cost per meter.

B. Advancing clean cooking transition

Another key observation from the modelling analysis in Chapter 5 and Chapter 6 is that clean cooking is very often a powerful lever for major shifts in household energy mix and use, including reduced inequalities and other social and environmental benefits.

1. **Facilitating the introduction of electric cooking tariffs**: Global experience suggests that introducing electric cooking tariffs can support the adoption of clean cooking solutions, particularly when aligned with inclusive energy transition strategies. Drawing on examples from China, India, and Indonesia – countries that have substantially reduced populations without access to clean cooking within a decade (IEA, 2023a) – local governments in partnership with utilities may consider exploring electric cooking tariffs designed to remain accessible and avoid pushing consumers into higher rate classes.
   A notable example is the cooking tariff recently introduced by the Ugandan Electricity Regulatory Authority, which uses a declining block tariff structure a declining block tariff for domestic consumers to displace charcoal and other biomass sources of cooking fuel and incentivize cooking with electricity. This tariff structure allows for differentiated pricing based on energy consumption, with lower rates applied to units of electricity consumed beyond a specified monthly threshold, thereby making electric cooking more

accessible and affordable for households. similar tariff mechanisms could be adapted to different local contexts to bolster clean cooking initiatives and promote equitable energy access.

2. **Integrating cooking strategies into broader electricity access initiatives by cities**: A critical recommendation emerging from recent discussions on clean cooking in Africa is the need for the explicit integration of clean cooking targets within broader power sector planning and electrification strategies at both local and national levels. In contexts where power sector planning is typically centralized, as is common in SSA, local governments could develop or enhance their local data and information infrastructure – such as pertaining to local adoption trends, economics, impact of incentives – to better inform national implementation agencies on their local clean cooking targets.
3. **Empowering local governments as key implementers**: While many governments have established clean cooking targets and policies, a significant gap remains in the resourcing and authority needed to drive implementation. With about 90% of the population without clean cooking access living in countries with dedicated implementation agencies (IEA, 2023a), there is a key opportunity for local governments, to step in as the operational arms of these national agencies. By becoming functional extensions of national efforts, local governments can play a pivotal role in turning clean cooking plans into tangible, on-the-ground actions.
4. **Driving innovation in delivery models**: The success of clean cooking initiatives may depend not only on policy but also on innovative business models that enhance consumer access to electric and other clean cooking appliances. Supporting upfront cost financing schemes, such as on-bill financing for efficient appliances (e.g. PayGo models) or the use of local capital to provide loans to individual customers to buy clean cookstoves, can significantly boost clean cooking adoption. The success stories from India and Indonesia highlight the crucial role of local companies and domestic capital markets, which provide essential financing both to customers and to businesses within the clean cooking sector. Access to domestic financing is especially vital for small- and medium-sized enterprises, enabling more firms to enter the market and increasing consumer access to clean cookstoves (IEA, 2023a).

7.2.2. Local data infrastructure and research capacity enable context-specific energy planning

Another central recommendation emerging from the discussion in section 7.1 is the importance of generating and utilizing local data to highlight urban specificities that can guide both national and local policy implementation. This highlights the other twin issue on the need to build local research expertise, particularly within local governments, to empower local actors to conduct more detailed and context-specific modelling exercises and policy design.

1. **Facilitating access to local government data**. This research is an example of a successful collaboration that hinged on authorized access to datasets from the studied cities. Strengthening institutional capacity for subnational energy data management – where responsibilities for updating and curating key datasets are clearly defined – could improve data availability for academic and research communities. Such improved accessibility may, in turn, enhance the evidence base for local energy policy and planning.

2. **Institutionalise energy planning**. Energy modelling in Africa has until now had very limited influence on local policymaking decisions, as modelling efforts are generally limited to national energy planning exercises. Also, energy modelling remains a specialized area with limited expertise, with the sector facing ongoing challenges, putting pressure on local experts to learn new skills and adapt. Additionally, local organizations with expertise in energy modelling face competition from international organizations, which may offer more attractive compensation and career advancement opportunities (Mutiso *et al.*, 2022). Evidence from several South African municipalities indicates that embedding energy planning functions within local government structures may help attract specialized talent, expand local expertise, and foster robust, data-driven decision-making. Establishing a dedicated municipal energy office, for example, can support internal research efforts, coordinate stakeholder collaboration, and integrate energy and climate action planning into broader municipal strategies.
3. **Leverage partnerships with key sector stakeholders.** A strengthened collaboration between local governments with academic research institutions, the government and the industry – particularly local organisations with excellent energy research skills – is essential to build a large pool of experts with cutting-edge technical skills on urban energy modelling. Such partnerships could include sponsoring graduate students for energy-related studies, secondment of local experts to municipal institutions, or facilitating data access to the research community.

7.2.3. Enabling economic equity in complementarity to energy-focused policies reduce inequalities

As highlighted earlier in this discussion in section 7.1, income inequality is closely tied to energy disparities, with the IR PAMs scenario (section 6.3) showing that a fairer income distribution could complement energy-focuses PAMs in reducing these inequalities. While traditional methods like taxation and cash transfers are effective in addressing inequality and poverty in the short term, the energy transition offers a unique opportunity to tackle these issues more directly. In a world where wealth is built through asset ownership, a decentralised energy future could enable individuals to build wealth by owning and operating distributed generation assets (DERs). Policies that encourage consumer participation, such as peer to peer transactions, net billing etc, can empower less affluent communities to use their generation assets and participate in grid transactions, thereby creating wealth and reducing inequalities.

As the shift to electric cooking gains momentum, there is a significant risk that local businesses and households, particularly in smaller cities, will lose their revenues and livelihoods due to reduced demand for charcoal. Managing the social and economic impact on communities dependent on the charcoal trade is crucial for a successful transition to clean cooking. Local policymakers could provide strategic guidance to support a just transition for these workers, including **reskilling initiatives** that open up long-term employment opportunities, potentially within the clean cooking industry.

7.2.4. Municipal authorities are in a unique position to influence equity outcomes despite limited powers

Evaluating the key mechanisms for creating a more equitable energy landscape at the city level against the powers held by local governments, it becomes evident that cities often lack sufficient authority or control over critical sectors or policy areas to enact substantial change. This is discussed in sections 3.1 and 7.1. However, there are several strategic areas where city leaders can effectively leverage their formal authority and soft influence to advance a fair and equitable urban energy agenda:

1. **Establishing metrics to track inequality in energy and emissions:** Operationalizing energy equity within municipal policy and program development is essential to ensure that equity outcomes in the energy transition are monitored and tracked. This process begins with setting clear, equitable goals and establishing metrics to measure progress. In this study, a preliminary framework of indicators was proposed, but this list can be expanded to include broader objectives like local air pollution reduction and job creation among others. Monitoring and evaluating these metrics can help municipalities tailor their strategies to address disparities more effectively.
2. **Building coalitions:** Achieving the scale and speed necessary to drive a fair and equitable energy transition is a task that extends beyond the capacities of municipal governments alone. To effectively catalyse this transformation, municipal leaders may leverage their positions of influence to forge strategic coalitions that amplify their efforts. By utilizing their "soft" power—such as diplomacy, advocacy, and convening authority—local governments can build alliances across sectors, including partnerships with other municipalities, regional and national governments, private sector stakeholders, civil society organizations, and international bodies. These coalitions may focus on shared goals and mutual benefits, working collaboratively to advocate for policy reforms, secure funding, and implement innovative solutions.
3. **Empowering municipalities implement just energy transitions:** Devolving more authority to municipalities, such granting city leaders greater control over key sectoral and socioeconomic policy areas could enable local governments to respond swiftly and effectively to the specific needs of their residents, tailoring solutions that are contextually relevant. However, this level of control may importantly be accompanied by devolved fiscal powers, enabling city leaders to raise revenues for targeted initiatives and allocate resources equitably. combining decision-making autonomy with revenue-generating capabilities may accelerate local progress toward sustainable and socially just energy systems.

7.3. Limitations and future research directions

Having discussed key findings and policy implications, it is essential to acknowledge several methodological, data-related, and scope-related limitations that readers should bear in mind in interpretating this study's results. Addressing these limitations in future research, is beyond the scope of a single PhD thesis, but could enhance both the validity and applicability of the conclusions drawn. This study employs a technoeconomic model to analyse energy consumption patterns and associated carbon footprints across six sub-Saharan African cities. The results should be understood within the context of three main limitations:

1. **Data constraints**

A key limitation of this study stems from insufficient granularity of available datasets. Particularly, most city-level datasets provided incomplete representations of residential activity data, necessitating the adaptation of synthetic data models from existing literature to estimate quintile-level variations. While these models were rigorously designed and validated (see Chapter 3), their use introduces complexity and potential systematic biases.

Future studies could undertake more detailed data collection – requiring substantial time, funding, and institutional support – to develop more comprehensive datasets. This could include data collection on:

- Granular household energy consumption data across diverse household types.
- Detailed data on productive use of energy at the urban scale.
- Time-series data to capture temporal evolutions in energy inequalities.
- Integration of data on environmental co-impacts, particularly local air pollution.
- Socioeconomic indicators, such as employment and skills development, to gauge the broader developmental impacts of energy transitions

2. Methodological limitations

The UHEM modelling framework, while innovative, relies on several simplifying assumptions. These include:

- Linear relationships among variables and a limited ability to capture non-linear dynamics.
- Coarse temporal resolution that uses annual averages, which may not fully account for temporal variations in peak demand, seasonal energy use and short-term consumption behaviours
- Simplified household decision-making processes, which may overlook behavioural, social, and cultural factors influencing energy choices.
- Limited treatment of technological change and adoption, limiting insights into the rapid evolution of new technologies.

Building on the UHEM modelling framework, future research could:

- Incorporate behavioural and social parameters to capture nuanced household decision-making.
- Enhance temporal resolution, particularly for peak demand analysis and energy equity implications.
- Model dynamic feedback loops between energy access and broader economic development, improving the understanding of how energy choices and economic progress intertwine over time.
- Introduce system-dynamics approaches that more accurately reflect household heterogeneity and technological shifts.

3. Scope boundaries

this study's scope was largely limited to the residential sector, which while revealing important patterns of urban energy inequality, potentially provides limited information on wider city-scale energy dynamics. As a result, interdependencies with other sectors and systemic feedback loops remain underexplored. Future research could:

- Energy inequality dynamics in productive use sectors (i.e. commercial, industrial and agricultural)
- Interconnections between sectoral energy use patterns
- Delve into spatial analyses to reveal intra-urban disparities in access, cost, and quality of energy services
- Transport sector inequalities and their relationship to urban form
- Infrastructure investment patterns and their equity implications

These limitations notwithstanding, this thesis makes several valuable contributions to understanding urban energy transitions in Africa, which are summarised in section 8.3 below. The identified limitations suggest promising directions for future research that could build upon this foundation to develop even more comprehensive understanding of energy inequality dynamics in African urban contexts.

Chapter 8 : Conclusion

The unprecedented pace of urbanization in Sub-Saharan Africa, coupled with the region's aspiration for energy abundance and economic growth, presents both challenges and opportunities for urban energy transitions. This thesis set out to examine how alternative urban energy transition pathways, including and beyond those specified in existing climate action plans or energy strategies, could simultaneously meet the energy demands necessary for sustainable development, reduce inequalities in energy use and GHG emissions.

The research was motivated by several gaps in the existing literature. First, despite growing attention to urban energy systems, previous analyses have predominantly focused on national or regional scales, overlooking the urban dimension, where energy demand is rapidly growing and concentrated. This urban blind spot has resulted in incomplete understanding of how energy transition policies manifest at the municipal level, where implementation ultimately occurs. Second, while energy inequality has received increasing scholarly attention, granular analysis of energy use and emissions disparities across household income groups in African urban contexts remains notably scarce. Third, there is limited evidence assessing whether existing urban energy transition pathways have appropriately addressed equity considerations, and there is limited understanding of how various policy interventions might affect different socioeconomic groups.

To address these gaps, this thesis posed the central research question: How can alternative energy transition pathways in Sub-Saharan African cities address the disparities in energy access, use, and GHG emissions across different income groups while supporting urban development needs?

This overarching question was supported by four sub-questions examining: (1) patterns and drivers of urban energy consumption across all key sectors, (2) base year household energy use and emissions inequalities, (3) effectiveness of existing local energy and climate policies in addressing inequalities, and (4) potential of alternative pathways to promote more equitable outcomes.

This chapter presents the conclusions on the question and sub-questions, by outlining the contributions of this thesis.

The contributions of this thesis are multifaceted, addressing critical gaps in the understanding of urban energy transitions in Sub-Saharan Africa. By employing a comprehensive, multi-city approach that integrates detailed data analysis, rigorous modelling techniques, and a nuanced exploration of equity considerations, this research provides new insights into the dynamics of energy use, inequality, and sustainable development in African urban contexts. The thesis has advanced both scholarly knowledge and practical policy development as detailed in the sections that follow:

8.1. Contribution to literature

This thesis makes a key contribution to the literature by conducting the first known review of local climate action plans (CAPs) across ten African cities. It evaluates the extent to which equity considerations – crucial for addressing pervasive socio-economic and energy disparities – are integrated into these plans. This focus on equity within urban energy and climate planning fills a critical gap in the existing body of work, which has only previously been undertaken for North American and European cities.

A key finding that diverges from previous analyses of European CAPs is that African CAPs more frequently foreground justice and equity as core components, even in their initial iterations. This heightened attention to equity emerges from two distinct drivers: first, the immediate visibility of existing inequalities in the African urban context, where issues such as energy poverty and inadequate infrastructure are readily observable realities that inherently shape stakeholder discussions; and second, the timing of African climate planning efforts, which benefited from the evolution of global climate action frameworks that increasingly emphasize equity considerations.

However, while equity is frequently acknowledged, it is often framed as an aspirational goal or co-benefit rather than a clearly defined, actionable priority. Many CAPs lack detailed strategies to translate equity objectives into measurable outcomes, revealing a disconnect between intention and execution.

8.2. Conceptual design and methodological contributions

This thesis makes several methodological contributions to the study of just urban energy transitions in African cities, particularly through its development of the Urban Household Energy Model (UHEM) framework and its application of comprehensive city-level datasets.

First, the research presents a novel analytical approach through the development and implementation of UHEM – a transparent and replicable bottom-up modelling framework, built on the LEAP platform, to analyse household energy inequalities in African urban contexts. This bottom-up framework integrates city-specific socio-economic data with detailed end-use energy demand modelling. For each city, households are stratified into quintiles by income and electrification status, enabling a nuanced analysis of energy consumption and GHG emissions at the household level, energy services and energy carriers.

Second, this study represents the first known application of comprehensive African city-level energy datasets for inequality analysis. Through unique access to detailed municipal data from six diverse urban areas - ranging from metropolitan centres like Cape Town to smaller towns like Tsévié - the research establishes new benchmarks for data granularity in African urban energy analysis. The successful collection, validation, and analysis of these datasets demonstrates the feasibility of detailed urban energy modelling in data-sparse environments, while also highlighting specific areas where data collection efforts should be prioritized. The thesis augments these datasets through various modelling techniques, such as the calibration of city-level energy balances and the use of logit and Weibull functions to address data gaps, while maintaining data fidelity. The author’s work with cities was clearly outlined at the outset of this thesis (section 1.4), while the contribution to knowledge is summarised in the next sub-section of this Conclusion (section 8.3). The dataset developed in this thesis is made available as online Supplementary Information, enabling other researchers to use it for further studies.

Third, the research's multi-city comparative framework offers methodological insights through its careful selection of case studies representing different urban typologies. The inclusion of cities varying in size, economic structure, and geographic location enables robust comparative analysis while revealing how different urban characteristics influence energy inequality patterns, offering meaningful, policy-relevant research across the continent’s diverse urban landscapes.

8.3. Contribution to knowledge of urban energy transitions in SSA

This thesis advances our understanding of urban energy transitions in Sub-Saharan Africa through several novel findings that challenge existing assumptions and provide new insights for both scholarship and practice. The conclusion here combines the analytical findings discussed in section 7.1 with the implications for policy in 7.2.

This thesis has advanced analysis and understanding of the sensitivity of policies and measures (PAMs) to context-specific urban characteristics when addressing energy and emissions inequalities. The comparative analysis of six diverse cities in Africa reveals significant heterogeneity in urban energy and emissions profiles both across and within cities, such as Gini coefficients of household energy use or per capita electricity consumption and various other indicators of sustainability (Chapter 4). The results have also demonstrated how this heterogeneity results in varied equity outcomes even when the cities are subjected to the same PAMs (section 6.2). This evidence challenges the notion of one-size-fits-all approaches to urban energy policy design, particularly when equitable outcomes are the focus. The thesis then argues that addressing this contextual sensitivity of equity-focused PAMs requires three key elements: i) strengthening municipal data infrastructure to facilitate access to local data, ii) institutionalizing local energy planning capacity through dedicated municipal energy offices/units to attract talent and stimulate demand for local skills in energy analysis, and iii) fostering collaboration with local research institutions to nurture a community of practice on energy modelling (section 7.2.2). The thesis provides an example of how collaboration with six African cities demonstrates the feasibility and value of developing context-specific datasets and analysis to guide more equitable urban energy planning.

The thesis has further explored the complex role of electricity in shaping socio-economic conditions and highlighted significant disparities in its consumption patterns across and within cities, challenging the notion that simply achieving broad grid access will ensure equitable benefits. The analysis reveals that electricity consumption closely correlates with GDP per capita, solidifying its role as a key enabler of economic development (Figure 20) while in most instances electricity is also the most unevenly distributed energy carrier across household quintiles. Notably, the findings have demonstrated that high electricity access rates in the base years do not necessarily translate to equitable use of energy – for instance, cities like Dakar, Cape Town, and Yaoundé maintain significant disparities in electricity use despite high electrification rates (section 4.2.1). These inequalities resonate with income, and other urban characteristics, limiting both productive opportunities and overall welfare. Moving beyond traditional top-down approaches to access improvement, the scenario modelling analysis has demonstrated that a decentralised approach to electrification, most often yields some of the highest gains in reducing inequalities while improving economic welfare (section 5.2 and 6.2). The thesis then posited that empowering urban areas to integrate decentralized forms of generation would require a number of measures including i) regulatory reforms to support local-level participation in grid asset ownerships, ii) a more explicit integration of distributed resources in local as well as national energy planning and iii) a reimagined utility business model that ensures that benefits of a bottom-up decentralised grid are equitably distributed (section 7.2.1).

This analysis has revealed a hierarchy in urban inequalities, with income disparities most often outweighing inequalities in GHG emissions, and both surpassing the inequalities in household energy consumption, as measured by the Gini coefficient (Chapter 4). In other words, income inequality is greater than inequality in GHG emissions, which is greater than inequality in household energy use. This hierarchical relationship persists across all studied cities despite their varying economic and social contexts, suggesting that energy consumption, up to a certain level, is essential for well-being, making it one of the first needs met across all income levels. The thesis has demonstrated that while households maintain a level of energy use as in the base year even under income constraints, the underlying income disparities remain a powerful driver of energy access inequalities. The scenario analysis (section 6.3) further supported this conclusion, demonstrating that policies aimed at redistributing income (IR PAMs) can, in some instances, yield more equitable outcomes than interventions focusing solely on energy measures. Ultimately, this evidence challenges current strategies that solely focus on energy PAMs to achieve equitable urban transitions. The findings suggest, rather, that comprehensive approaches – combining energy-focused measures with income-related interventions – may prove more effective in achieving equitable and sustainable urban energy transitions. The thesis therefore argues for enabling community wealth creation through policies that encourage consumer participation – such as peer-to-peer transactions or net billing – by leveraging their own distributed resource generation assets to participate in grid transactions, ultimately reducing income inequalities (section 7.2.3).

This thesis has quantified to what extent current energy use in African cities falls short of providing the decent living standards consistent with global benchmarks, emphasizing the need for transformational changes rather than incremental improvements. Meeting the Modern Energy Minimum of 1000 kWh per capita would require dramatic expansions of urban energy systems and greater focus on electricity's share in final energy demand, which currently lags the rest of the world (section 4.1). Moreover, the analysis shows consistently low levels of productive use of energy across the cities, as exemplified by the very low shares of either commercial and industrial sectors in final energy demand, highlighting limited economic diversification and the scale of the challenge ahead (section 4.2). In response, the research had identified several key mechanisms through which municipalities can advance transformative change. Although many necessary reforms lie beyond municipal jurisdiction (section 2.3), cities hold valuable levers of influence within their formal authority and informal networks. By i) institutionalizing energy justice principles in municipal planning, ii) establishing metrics to monitor inequalities, and iii) forging coalitions across sectors and governance levels, municipal leaders can advance a fair, equitable urban energy agenda (section 7.2.4)

The thesis has equally provided useful insights into the equity impacts of different policy approaches in African urban contexts. The analysis has revealed that current stated policies (STEPS), despite often lacking clearly actionable measures on equity, can achieve meaningful reductions in household energy use and emissions inequalities (section 5.2). It should be noted that these reductions depend on implementation of what is assumed in the STEPS scenario. Fully implementing existing PAMs is important. Moreover, the study has showed that clean cooking and electricity access PAMs are the most powerful levers for reducing household energy inequalities, though with notably different patterns of impact across cities (section 5.2.2). However, the research has demonstrated that more ambitious targets, through a community-led, bottom-up approach as modelled in the Blues scenario, can yield substantially better equity outcomes. Importantly, the analysis has shown that not all clean energy interventions yield positive equity outcomes - the Municipal-led, top down (Harmony) scenario's emphasis on LPG as a transition fuel for cooking actually widened energy use inequality gaps in several cities relative to STEPS (section 6.2). Again, the analysis demonstrated that clean cooking electrification and decentralised energy access in the Blues scenario are the biggest levers in reducing inequalities. However, the findings have revealed a non-linear relationship between clean energy access and inequality reduction, suggesting diminishing returns beyond certain thresholds of clean energy adoption in advancing equity goals (section 6.2). Also, the study cautions that transitioning to electric cooking could undermine local charcoal-based livelihoods, especially in smaller cities, underscoring the need for just transition strategies, including reskilling programs, to secure long-term employment opportunities (section 7.2.3).

The analysis has established a strong correlation between urban scale, energy efficiency, and clean energy adoption with larger urban economies – Cape Town, Nairobi, and Dakar – demonstrating both higher efficiency levels and higher shares of clean energy than smaller cities (sections 4.1.1, 4.2 and 6.2). In other words, the size of a city matters. While technological advancement and economic development patterns largely explain these differences, the analysis has also revealed that abundant energy use often corresponds with higher shares of clean fuels. However, this relationship is not uniform; within cities, wealthier households consistently enjoy more equitable access to clean energy services, perpetuating a cycle of economic and energy inequality (Chapter 4). Rising penetration of distributed forms of energy, under the Blues scenario, also introduces new equity challenges as early adopters tend to be more affluent, potentially exacerbating cost-shifting and tariff inequities (section 7.1.5). At the same time, the scenario analysis in Chapter 6 establishes that smaller cities and lower-income households respond more dramatically to policy interventions, experiencing substantial gains in energy access and use – sometimes by orders of magnitude – when subjected to ambitious electrification and income redistribution measures. Given this higher policy responsiveness in smaller cities, the thesis argues for enhanced municipal authority over energy planning and implementation, supported by appropriate fiscal powers to enable contextually relevant solutions (section 7.2.4).

In conclusion, this thesis demonstrated that while current policies show promise in reducing inequalities, realizing truly transformative change demands both ambitious clean energy targets and different approaches to energy governance. Perhaps most significantly, this research establishes that there can be no universal pathway to urban energy equity; rather, successful transitions must be grounded in detailed understanding of local contexts while fostering innovative institutional arrangements that enable cities to become central actors in shaping more equitable energy futures.

References

Abbasabadi, N. and Ashayeri, M. (2019) ‘Urban energy use modeling methods and tools: A review and an outlook’, *Building and Environment*, 161, p. 106270. Available at: https://doi.org/10.1016/j.buildenv.2019.106270.

Acheampong, A.O. *et al.* (2022) ‘Effects of income inequality and governance on energy poverty alleviation: Implications for sustainable development policy’, *Utilities Policy*, 78, p. 101403. Available at: https://doi.org/10.1016/j.jup.2022.101403.

Acheampong, A.O., Dzator, J. and Shahbaz, M. (2021) ‘Empowering the powerless: Does access to energy improve income inequality?’, *Energy Economics*, 99, p. 105288. Available at: https://doi.org/10.1016/j.eneco.2021.105288.

ACUTO, M. and RAYNER, S. (2016) ‘City networks: breaking gridlocks or forging (new) lock-ins?’, *International Affairs*, 92(5), pp. 1147–1166. Available at: https://doi.org/10.1111/1468-2346.12700.

Adeleye, B.N. *et al.* (2021) ‘Energy use and the role of per capita income on carbon emissions in African countries’, *PLOS ONE*, 16(11), p. e0259488. Available at: https://doi.org/10.1371/journal.pone.0259488.

AFREC (2022) *Energy Usage by Businesses in Africa*. Algiers. Available at: https://au-afrec.org/sites/default/files/2022-11/EN_Coal%20In%20the%20African%20Landscape_WEB.pdf (Accessed: 10 January 2025).

African Union Commission (2015) *Agenda 2063 : The Africa We Want*. Available at: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/Agenda2063_Popular_Version_English.pdf (Accessed: 13 July 2023).

Akrofi, M.M., McLellan, B.C. and Okitasari, M. (2024) ‘Characterizing “injustices” in clean energy transitions in Africa’, *Energy for Sustainable Development*, 83, p. 101546. Available at: https://doi.org/10.1016/j.esd.2024.101546.

Akrofi, M.M. and Okitasari, M. (2022) ‘Integrating solar energy considerations into urban planning for low carbon cities: A systematic review of the state-of-the-art’, *Urban Governance*, 2(1), pp. 157–172. Available at: https://doi.org/10.1016/j.ugj.2022.04.002.

Alvaredo, F. *et al.* (2016) *Distributional National Accounts (DINA) Guidelines: Concepts and Methods used in WID.world*, *WID.world Working Paper Series*. Available at: http://piketty.pse.ens.fr/files/Alvaredoetal2016WIDworld.pdf (Accessed: 10 January 2025).

Ambole, A. *et al.* (2021) ‘A Review of Energy Communities in Sub-Saharan Africa as a Transition Pathway to Energy Democracy’, *Sustainability*, 13(4), p. 2128. Available at: https://doi.org/10.3390/su13042128.

Amegah, A.K. and Agyei-Mensah, S. (2017) ‘Urban air pollution in Sub-Saharan Africa: Time for action’, *Environmental Pollution* [Preprint]. Available at: https://doi.org/10.1016/j.envpol.2016.09.042.

Ang, B.W. (2006) ‘Monitoring changes in economy-wide energy efficiency: From energy–GDP ratio to composite efficiency index’, *Energy Policy*, 34(5), pp. 574–582. Available at: https://doi.org/10.1016/j.enpol.2005.11.011.

Ang, B.W. and Goh, T. (2018) ‘Bridging the gap between energy-to-GDP ratio and composite energy intensity index’, *Energy Policy*, 119, pp. 105–112. Available at: https://doi.org/10.1016/j.enpol.2018.04.038.

Anguelovski, I. *et al.* (2020) ‘Expanding the Boundaries of Justice in Urban Greening Scholarship: Toward an Emancipatory, Antisubordination, Intersectional, and Relational Approach’, *Annals of the American Association of Geographers*, 110(6), pp. 1743–1769. Available at: https://doi.org/10.1080/24694452.2020.1740579.

Ansarin, M. *et al.* (2022) ‘A review of equity in electricity tariffs in the renewable energy era’, *Renewable and Sustainable Energy Reviews*, 161, p. 112333. Available at: https://doi.org/10.1016/j.rser.2022.112333.

Appiah, M., Li, F. and Korankye, B. (2021) ‘Modeling the linkages among CO2 emission, energy consumption, and industrialization in sub-Saharan African (SSA) countries’, *Environmental Science and Pollution Research*, 28(29), pp. 38506–38521. Available at: https://doi.org/10.1007/s11356-021-12412-z.

Asongu, Simplice A. and Odhiambo, N.M. (2021) ‘Inequality and renewable energy consumption in Sub-Saharan Africa: implication for high income countries’, *Innovation: The European Journal of Social Science Research*, pp. 1–17. Available at: https://doi.org/10.1080/13511610.2020.1861442.

Asongu, Simplice A and Odhiambo, N.M. (2021) ‘The green economy and inequality in Sub-Saharan Africa: Avoidable thresholds and thresholds for complementary policies’, *Energy Exploration & Exploitation*, 39(3), pp. 838–852. Available at: https://doi.org/10.1177/0144598720984226.

Athawale, R. and Felder, F. (2016) ‘Residential Rate Design and Death Spiral for Electric Utilities: Efficiency and Equity Considerations’, in *Future of Utilities Utilities of the Future*. Elsevier, pp. 193–209. Available at: https://doi.org/10.1016/B978-0-12-804249-6.00010-5.

Avelino, F. *et al.* (2024a) ‘Mapping the diversity & transformative potential of approaches to sustainable just cities’, *Urban Transformations*, 6(1), p. 5. Available at: https://doi.org/10.1186/s42854-023-00058-8.

Avelino, F. *et al.* (2024b) ‘Mapping the diversity & transformative potential of approaches to sustainable just cities’, *Urban Transformations*, 6(1), p. 5. Available at: https://doi.org/10.1186/s42854-023-00058-8.

Avila, N. *et al.* (2017) ‘The energy challenge in sub-Saharan Africa: A guide for advocates and policy makers’, *Generating energy for sustainable and equitable development* [Preprint]. Available at: https://doi.org/10.13140/RG.2.2.25037.44001.

Ayaburi, J. *et al.* (2020) ‘Measuring “Reasonably Reliable” access to electricity services’, *The Electricity Journal*, 33(7), p. 106828. Available at: https://doi.org/10.1016/j.tej.2020.106828.

Baker, E. *et al.* (2023) ‘Metrics for Decision-Making in Energy Justice’, *Annual Review of Environment and Resources*, 48(1), pp. 737–760. Available at: https://doi.org/10.1146/annurev-environ-112621-063400.

Baker, L. and Phillips, J. (2019) ‘Tensions in the transition: The politics of electricity distribution in South Africa’, *Environment and Planning C: Politics and Space*, 37(1), pp. 177–196. Available at: https://doi.org/10.1177/2399654418778590.

Baker, S., DeVar, S. and Prakash, S. (2019) *The Energy Justice Workbook*. Available at: https://iejusa.org/wp-content/uploads/2019/12/The-Energy-Justice-Workbook-2019-web.pdf (Accessed: 10 January 2025).

Ballesteros-Arjona, V. *et al.* (2022) ‘What are the effects of energy poverty and interventions to ameliorate it on people’s health and well-being?: A scoping review with an equity lens’, *Energy Research & Social Science*, 87, p. 102456. Available at: https://doi.org/10.1016/j.erss.2021.102456.

Baloch, M.A. *et al.* (2020a) ‘Analyzing the relationship between poverty, income inequality, and CO2 emission in Sub-Saharan African countries’, *Science of The Total Environment*, 740, p. 139867. Available at: https://doi.org/10.1016/j.scitotenv.2020.139867.

Baloch, M.A. *et al.* (2020b) ‘Analyzing the relationship between poverty, income inequality, and CO2 emission in Sub-Saharan African countries’, *Science of The Total Environment*, 740, p. 139867. Available at: https://doi.org/10.1016/j.scitotenv.2020.139867.

Bansard, J.S., Pattberg, P.H. and Widerberg, O. (2017) ‘Cities to the rescue? Assessing the performance of transnational municipal networks in global climate governance’, *International Environmental Agreements: Politics, Law and Economics*, 17(2), pp. 229–246. Available at: https://doi.org/10.1007/s10784-016-9318-9.

Bardazzi, R., Bortolotti, L. and Pazienza, M.G. (2021) ‘To eat and not to heat? Energy poverty and income inequality in Italian regions’, *Energy Research & Social Science*, 73, p. 101946. Available at: https://doi.org/10.1016/j.erss.2021.101946.

Bawakyillenuo, S. *et al.* (2018) ‘Sustainable Energy Transitions in Sub-Saharan African Cities: The Role of Local Government’, *Urban Energy Transition*, pp. 529–551. Available at: https://doi.org/10.1016/b978-0-08-102074-6.00042-5.

Bazilian, M. *et al.* (2012) ‘Energy access scenarios to 2030 for the power sector in sub-Saharan Africa’, *Utilities Policy*, 20(1), pp. 1–16. Available at: https://doi.org/10.1016/j.jup.2011.11.002.

Becker, S. and Naumann, M. (2017) ‘Energy democracy: Mapping the debate on energy alternatives’, *Geography Compass*, 11(8). Available at: https://doi.org/10.1111/gec3.12321.

Bhattacharyya, S.C. and Timilsina, G.R. (2010) ‘Modelling energy demand of developing countries: Are the specific features adequately captured?’, *Energy Policy*, 38(4), pp. 1979–1990. Available at: https://doi.org/10.1016/j.enpol.2009.11.079.

Blimpo, M.P. and Cosgrove-Davies, M. (2019) *Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact*, *Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact*. Available at: https://doi.org/10.1596/978-1-4648-1361-0.

Böhringer, C. and Rutherford, T.F. (2006) ‘Combining Top-Down and Bottom-Up in Energy Policy Analysis: A Decomposition Approach’, *SSRN Electronic Journal* [Preprint]. Available at: https://doi.org/10.2139/ssrn.878433.

Bouzarovski, S. (2018) *Energy Poverty*. Cham: Springer International Publishing. Available at: https://doi.org/10.1007/978-3-319-69299-9.

Brockway, A.M., Conde, J. and Callaway, D. (2021) ‘Inequitable access to distributed energy resources due to grid infrastructure limits in California’, *Nature Energy*, 6(9), pp. 892–903. Available at: https://doi.org/10.1038/s41560-021-00887-6.

Brown, Marilyn A *et al.* (2020) ‘High energy burden and low-income energy affordability: conclusions from a literature review’, *Progress in Energy*, 2(4), p. 042003. Available at: https://doi.org/10.1088/2516-1083/abb954.

Brown, Marilyn A. *et al.* (2020) ‘The persistence of high energy burdens: A bibliometric analysis of vulnerability, poverty, and exclusion in the United States’, *Energy Research & Social Science*, 70, p. 101756. Available at: https://doi.org/10.1016/j.erss.2020.101756.

Burke, M.J. and Stephens, J.C. (2017) ‘Energy democracy: Goals and policy instruments for sociotechnical transitions’, *Energy Research & Social Science*, 33, pp. 35–48. Available at: https://doi.org/10.1016/j.erss.2017.09.024.

C40 (2021) *Climate Action Planning (CAP) Africa*. Available at: https://www.c40.org/tags/cap-africa.

C40 (2022a) *Mapped: Cities with a climate action plan*. Available at: https://www.c40knowledgehub.org/s/article/Mapped-Cities-with-a-climate-action-plan?language=en_US (Accessed: 9 October 2024).

C40 (2022b) *Mapped: Cities with a climate action plan*. Available at: https://www.c40knowledgehub.org/s/article/Mapped-Cities-with-a-climate-action-plan?language=en_US (Accessed: 23 November 2024).

C40 (2023) *Achieving the Just Transition: A Toolkit for City Leaders Across the Globe*. Available at: https://www.c40.org/news/achieving-the-just-transition-toolkit-for-city-leaders/ (Accessed: 10 January 2025).

Cabello Eras, J.J. *et al.* (2022) ‘The inequality of electricity consumption in Colombia. Projections and implications’, *Energy*, 249, p. 123711. Available at: https://doi.org/10.1016/j.energy.2022.123711.

Carley, S. and Konisky, D.M. (2020) ‘The justice and equity implications of the clean energy transition’, *Nature Energy*, 5(8), pp. 569–577. Available at: https://doi.org/10.1038/s41560-020-0641-6.

Castán Broto, V. and Westman, L. (2017) ‘Just sustainabilities and local action: evidence from 400 flagship initiatives’, *Local Environment*, 22(5), pp. 635–650. Available at: https://doi.org/10.1080/13549839.2016.1248379.

CCT (2021) *The Cape Town State of Energy and Carbon 2021*. Cape Town. Available at: https://resource.capetown.gov.za/documentcentre/Documents/City research reports and review/CT_State_of Energy_and_Carbon_Report_2021.pdf.

CDP (2024) *Cities*. Available at: https://www.cdp.net/en/cities (Accessed: 26 December 2024).

Certomà, C. *et al.* (2023) 'Beyond Income and Inequality: The Role of Socio-political Factors for Alleviating Energy Poverty in Europe', *Social Indicators Research*, 169(1–2), pp. 167–208. Available at: https://doi.org/10.1007/s11205-023-03148-z.

Chancel, L. and Piketty, T. (2015) 'Carbon and inequality: From Kyoto to Paris'. Available at: https://doi.org/10.13140/RG.2.1.3536.0082.

Clement, V. *et al.* (2021) *Groundswell Part 2: Acting on Internal Climate Migration*. Washington, DC. Available at: http://hdl.handle.net/10986/36248 (Accessed: 26 December 2024).

Climate Transparency (2018) *Brown to Green: The G20 Transition to a Low-Carbon Economy*. Berlin. Available at: https://www.climate-transparency.org/wp-content/uploads/2019/01/2018-BROWN-TO-GREEN-REPORT-FINAL.pdf.

Coalition for Urban Transitions (2019) *Climate Emergency, Urban Opportunity*. London and Washington, DC. Available at: https://urbantransitions.global/urban-opportunity/ (Accessed: 26 December 2024).

Combes, P.-P. *et al.* (2023) *An Anatomy of Urbanization in Sub-Saharan Africa*. Available at: https://documents1.worldbank.org/curated/en/099415311272320571/pdf/IDU0faef6c000aaba0485209f0e08928760d9a57.pdf (Accessed: 10 January 2025).

CoMSSA (2024a) *Climate action and energy access planning achievements*. Available at: https://comssa.org/en/project_pipeline (Accessed: 9 October 2024).

CoMSSA (2024b) *Covenant of Mayors in Sub-Saharan Africa*. Available at: https://comssa.org/about/#.

Daioglou, V., Ruijven, B.J. Van and Vuuren, D.P. Van (2012) 'Model projections for household energy use in developing countries', *Energy*, 37(1), pp. 601–615. Available at: https://doi.org/10.1016/j.energy.2011.10.044.

Dioha MO (2017) 'Energy System Models for Sub-Saharan African Countries - A Systematic Review', *Journal of Sustainable Energy*, 8(4).

Dioha, M.O. and Emodi, N.V. (2019) 'Investigating the impacts of energy access scenarios in the Nigerian household sector by 2030', *Resources*, 8(3), p. 127. Available at: https://doi.org/10.3390/resources8030127.

Dioha, M.O. and Kumar, A. (2020a) 'Exploring sustainable energy transitions in sub-Saharan Africa residential sector: The case of Nigeria', *Renewable and Sustainable Energy Reviews*, 117, p. 109510. Available at: https://doi.org/10.1016/j.rser.2019.109510.

Dioha, M.O. and Kumar, A. (2020b) 'Exploring sustainable energy transitions in sub-Saharan Africa residential sector: The case of Nigeria', *Renewable and Sustainable Energy Reviews*, 117, p. 109510. Available at: https://doi.org/10.1016/j.rser.2019.109510.

Djenontin, I.N.S. and Meadow, A.M. (2018) 'The art of co-production of knowledge in environmental sciences and management: lessons from international practice', *Environmental Management*, 61(6), pp. 885–903. Available at: https://doi.org/10.1007/s00267-018-1028-3.

Dong, X.-Y. and Hao, Y. (2018) ‘Would income inequality affect electricity consumption? Evidence from China’, *Energy*, 142, pp. 215–227. Available at: https://doi.org/10.1016/j.energy.2017.10.027.

Dreborg, K.H. (1996) ‘Essence of backcasting’, *Futures*, 28(9), pp. 813–828. Available at: https://doi.org/10.1016/S0016-3287(96)00044-4.

EIA (2018) *How much electricity does an American home use?*, *U.S. Energy Information Administration*. Available at: https://www.eia.gov/tools/faqs/faq.php?id=97&t=4 (Accessed: 27 September 2020).

Ember (2024) *Electricity Data Explorer*. Available at: https://ember-energy.org/data/electricity-data-explorer/ (Accessed: 18 October 2024).

Estrada, F., Botzen, W.J.W. and Tol, R.S.J. (2017) ‘A global economic assessment of city policies to reduce climate change impacts’, *Nature Climate Change*, 7(6), pp. 403–406. Available at: https://doi.org/10.1038/nclimate3301.

Farquharson, D., Jaramillo, P. and Samaras, C. (2018) ‘Sustainability implications of electricity outages in sub-Saharan Africa’, *Nature Sustainability*, 1(10), pp. 589–597. Available at: https://doi.org/10.1038/s41893-018-0151-8.

Galvin, R. (2019) ‘Energy poverty research: A perspective from the poverty side’, in *Inequality and Energy: How Extremes of Wealth and Poverty in High Income Countries Affect CO2 Emissions and Access to Energy*. Available at: https://doi.org/10.1016/B978-0-12-817674-0.00010-2.

Galvin, R. (2020a) ‘Energy poverty research: A perspective from the poverty side’, in *Inequality and Energy*. Elsevier, pp. 221–248. Available at: https://doi.org/10.1016/B978-0-12-817674-0.00010-2.

Galvin, R. (2020b) *Inequality and Energy*, *Inequality and Energy*. Available at: https://doi.org/10.1016/c2018-0-02082-4.

Gastwirth, J.L. (1972) ‘The Estimation of the Lorenz Curve and Gini Index’, *The Review of Economics and Statistics*, 54(3), pp. 306–316. Available at: https://doi.org/10.2307/1937992.

Gouldson, A. *et al.* (2015) ‘Exploring the economic case for climate action in cities’, *Global Environmental Change*, 35, pp. 93–105. Available at: https://doi.org/10.1016/j.gloenvcha.2015.07.009.

Grubler, A. (2012) ‘Energy transitions research: Insights and cautionary tales’, *Energy Policy*, 50, pp. 8–16. Available at: https://doi.org/10.1016/j.enpol.2012.02.070.

Hawkins, E. and Sutton, R. (2009) ‘The Potential to Narrow Uncertainty in Regional Climate Predictions’, *Bulletin of the American Meteorological Society*, 90(8), pp. 1095–1108. Available at: https://doi.org/10.1175/2009BAMS2607.1.

Healy, N. and Barry, J. (2017) ‘Politicizing energy justice and energy system transitions: Fossil fuel divestment and a “just transition”’, *Energy Policy*, 108, pp. 451–459. Available at: https://doi.org/10.1016/j.enpol.2017.06.014.

Heaps, C. (2020) *Low Emissions Analysis Platform Training Exercise*. Stockholm Environment Institute.

Hickmann, T. and Stehle, F. (2019) ‘The Embeddedness of Urban Climate Politics in Multilevel Governance: A Case Study of South Africa’s Major Cities’, *The Journal of Environment & Development*, 28(1), pp. 54–77. Available at: https://doi.org/10.1177/1070496518819121.

Hiremath, R.B., Shikha, S. and Ravindranath, N.H. (2007) ‘Decentralized energy planning; modeling and application—a review’, *Renewable and Sustainable Energy Reviews*, 11(5), pp. 729–752. Available at: https://doi.org/10.1016/j.rser.2005.07.005.

Hirmer, S. *et al.* (2024) ‘Inconsistent measurement calls into question progress on electrification in sub-Saharan Africa’, *Nature Energy* [Preprint]. Available at: https://doi.org/10.1038/s41560-024-01609-4.

Hu, G., Ma, X. and Ji, J. (2019) ‘Scenarios and policies for sustainable urban energy development based on LEAP model – A case study of a postindustrial city: Shenzhen China’, *Applied Energy*, 238, pp. 876–886. Available at: https://doi.org/10.1016/j.apenergy.2019.01.162.

Hubacek, K. *et al.* (2017) ‘Global carbon inequality’, *Energy, Ecology and Environment*, 2(6), pp. 361–369. Available at: https://doi.org/10.1007/s40974-017-0072-9.

Ibitoye, F.I. (2013) ‘The millennium development goals and household energy requirements in Nigeria’, *SpringerPlus*, 2(1), pp. 1–9. Available at: https://doi.org/10.1186/2193-1801-2-529/FIGURES/7.

IEA (2019a) ‘Africa Energy Outlook 2019 – Analysis Scenarios.’, *World Energy Outlook Special Report*, p. 288. Available at: https://www.iea.org/reports/africa-energy-outlook-2019#energy-access%0Ahttps://www.iea.org/reports/africa-energy-outlook-2019#africa-case.

IEA (2019b) ‘Defining energy access: 2019 methodology’, November. Available at: https://www.iea.org/articles/defining-energy-access-2019-methodology (Accessed: 29 September 2020).

IEA (2021) *Empowering Cities for a Net Zero Future*. Paris. Available at: https://iea.blob.core.windows.net/assets/4d5c939d-9c37-490b-bb53-2c0d23f2cf3d/G20EmpoweringCitiesforaNetZeroFuture.pdf (Accessed: 26 December 2024).

IEA (2022a) *Africa Energy Outlook 2022*. Paris. Available at: https://www.iea.org/reports/africa-energy-outlook-2022 (Accessed: 26 December 2024).

IEA (2022b) *World Energy Outlook Special Report Africa Energy Outlook 2022*. Paris. Available at: https://www.iea.org/reports/africa-energy-outlook-2022 (Accessed: 11 January 2023).

IEA (2023a) *A Vision for Clean Cooking Access for All*. Available at: https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all/executive-summary (Accessed: 30 July 2024).

IEA (2023b) *Energy Statistics Data Browser*. Available at: https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=WORLD&fuel=Energy%20supply&indicator=TESbySource (Accessed: 18 October 2024).

IEA (2024a) *Electricity 2024*. Paris. Available at: https://www.iea.org/reports/electricity-2024 (Accessed: 23 October 2024).

IEA (2024b) *Empowering Urban Energy Transitions*. Available at: https://iea.blob.core.windows.net/assets/00f7d520-d517-473d-b357-5adb43c4a57e/EmpoweringUrbanEnergyTransitions.pdf (Accessed: 11 September 2024).

Igawa, M. and Managi, S. (2022) ‘Energy poverty and income inequality: An economic analysis of 37 countries’, *Applied Energy*, 306, p. 118076. Available at: https://doi.org/10.1016/j.apenergy.2021.118076.

IGES (2024) ‘List of Grid Emission Factors, version 11.4’. Institute for Global Environmental Strategies. Available at: https://pub.iges.or.jp/pub/iges-list-grid-emission-factors (Accessed: 14 April 2024).

Ikejemba, E.C.X. and Schuur, P.C. (2020) ‘The empirical failures of attaining the societal benefits of renewable energy development projects in Sub-Saharan Africa’, *Renewable Energy*, 162, pp. 1490–1498. Available at: https://doi.org/10.1016/j.renene.2020.08.052.

IRENA (2024) *Advancing renewables-based clean cooking: Key messages and outcomes*. Abu Dhabi. Available at: www.irena.org.

Jacobson, A., Milman, A.D. and Kammen, D.M. (2005) ‘Letting the (energy) Gini out of the bottle: Lorenz curves of cumulative electricity consumption and Gini coefficients as metrics of energy distribution and equity’, *Energy Policy*, 33(14), pp. 1825–1832. Available at: https://doi.org/10.1016/j.enpol.2004.02.017.

James, B.D. (2016) *The Gini Coefficient and Personal Inequality Measurement* . Ontario.

Jenkins, K. *et al.* (2016a) ‘Energy justice: A conceptual review’, *Energy Research & Social Science*, 11, pp. 174–182. Available at: https://doi.org/10.1016/j.erss.2015.10.004.

Jenkins, K. *et al.* (2016b) ‘Energy justice: A conceptual review’, *Energy Research & Social Science*, 11, pp. 174–182. Available at: https://doi.org/10.1016/j.erss.2015.10.004.

Jenkins, K., Sovacool, B.K. and McCauley, D. (2018) ‘Humanizing sociotechnical transitions through energy justice: An ethical framework for global transformative change’, *Energy Policy*, 117, pp. 66–74. Available at: https://doi.org/10.1016/j.enpol.2018.02.036.

Joe, H. (2023) *Measuring inequality: what is the Gini coefficient?*, *Our World in Data*. Available at: https://ourworldindata.org/what-is-the-gini-coefficient (Accessed: 21 August 2024).

Kahsai, M.S. *et al.* (2012) ‘Income level and the energy consumption-GDP nexus: Evidence from Sub-Saharan Africa’, *Energy Economics*, 34(3), pp. 739–746. Available at: https://doi.org/10.1016/j.eneco.2011.06.006.

Kartha, S. *et al.* (2020) *The Carbon Inequality Era: An assessment of the global distribution of consumption emissions among individuals from 1990 to 2015 and beyond*. Available at: https://www.sei.org/publications/the-carbon-inequality-era/.

Kebede, E., Kagochi, J. and Jolly, C.M. (2010) ‘Energy consumption and economic development in Sub-Sahara Africa’, *Energy Economics*, 32(3), pp. 532–537. Available at: https://doi.org/10.1016/j.eneco.2010.02.003.

Khan, F. and Heinecker, P. (2018) ‘Inequality and energy: Revisiting the relationship between disparity of income distribution and energy use from a complex systems perspective’, *Energy*

Research & Social Science, 42, pp. 184–192. Available at: https://doi.org/10.1016/j.erss.2018.03.026.

Kojima, M. *et al.* (2016) *Who Uses Electricity in Sub-Saharan Africa?, World Bank Policy Research Working Paper 7889*.

Kraft, J.; Kraft, A. (1978) ‘Relationship between energy and GNP’, *J. Energy Dev.; (United States)* [Preprint].

Krieger, T. and Meierrieks, D. (2019) ‘Income inequality, redistribution and domestic terrorism’, *World Development*, 116, pp. 125–136. Available at: https://doi.org/10.1016/j.worlddev.2018.12.008.

Kumar, A., Zimmerman, S. and Arroyo-Arroyo, F. (2021) *Myths and Realities of “Informal” Public Transport in Developing Countries: Approaches for Improving the Sector, SSATP Africa Transport Policy Program*.

Lecocq, F. and Winkler, H. (2023) ‘Mitigation and Development Pathways in the Near to Mid-term’, in *Climate Change 2022 - Mitigation of Climate Change*. Cambridge University Press, pp. 409–502. Available at: https://doi.org/10.1017/9781009157926.006.

Lee, C.-C. and Chang, C.-P. (2007) ‘Energy consumption and GDP revisited: A panel analysis of developed and developing countries’, *Energy Economics*, 29(6), pp. 1206–1223. Available at: https://doi.org/10.1016/j.eneco.2007.01.001.

Liu, G. *et al.* (2021) ‘LEAP-WEAP analysis of urban energy-water dynamic nexus in Beijing (China)’, *Renewable and Sustainable Energy Reviews*, 136, p. 110369. Available at: https://doi.org/10.1016/j.rser.2020.110369.

Loulou, R. *et al.* (2016) *Documentation for the TIMES Model*. Available at: https://iea-etsap.org/docs/Documentation_for_the_TIMES_Model-Part-I_July-2016.pdf (Accessed: 10 January 2025).

Louw, K. *et al.* (2008) ‘Determinants of electricity demand for newly electrified low-income African households’, *Energy Policy*, 36(8). Available at: https://doi.org/10.1016/j.enpol.2008.02.032.

Maji, I.K. (2019) ‘Impact of clean energy and inclusive development on CO2 emissions in sub-Saharan Africa’, *Journal of Cleaner Production*, 240, p. 118186. Available at: https://doi.org/10.1016/j.jclepro.2019.118186.

Makinde, O.O. (2012) ‘Urbanization, housing and environment: Megacities of Africa ’, *International Journal of Development and Sustainability*, 1(3).

Makonese, T., Ifegbesan, A.P. and Rampedi, I.T. (2018) ‘Household cooking fuel use patterns and determinants across southern Africa: Evidence from the demographic and health survey data’, *Energy and Environment*, 29(1), pp. 29–48. Available at: https://doi.org/10.1177/0958305X17739475.

Mastrucci, A. *et al.* (2019) ‘Improving the SDG energy poverty targets: Residential cooling needs in the Global South’, *Energy and Buildings* [Preprint]. Available at: https://doi.org/10.1016/j.enbuild.2019.01.015.

McCall, B., Stone, A. and Tait, L. (2017a) ‘Kasese LEAP modelling technical report’, *Research Report Series* [Preprint], (May).

McCall, B., Stone, A. and Tait, L. (2017b) ‘Kasese LEAP modelling technical report’, *Research Report Series* [Preprint], (May).

McNamara, W. *et al.* (2022) ‘Seeking energy equity through energy storage’, *The Electricity Journal*, 35(1), p. 107063. Available at: https://doi.org/10.1016/j.tej.2021.107063.

McNeil, M.A. and Letschert, V.E. (2010) ‘Modeling diffusion of electrical appliances in the residential sector’, *Energy and Buildings*, 42(6), pp. 783–790. Available at: https://doi.org/10.1016/j.enbuild.2009.11.015.

Mehrara, M. (2007) ‘Energy consumption and economic growth: The case of oil exporting countries’, *Energy Policy* [Preprint]. Available at: https://doi.org/10.1016/j.enpol.2006.10.018.

Menegaki, A.N. and Tugcu, C.T. (2016) ‘Rethinking the energy-growth nexus: Proposing an index of sustainable economic welfare for Sub-Saharan Africa’, *Energy Research and Social Science* [Preprint]. Available at: https://doi.org/10.1016/j.erss.2016.04.009.

Millward-Hopkins, J. and Oswald, Y. (2023) ‘Reducing global inequality to secure human wellbeing and climate safety: a modelling study’, *The Lancet Planetary Health*, 7(2), pp. e147–e154. Available at: https://doi.org/10.1016/S2542-5196(23)00004-9.

Monyei, C.G. *et al.* (2018) ‘Examining energy sufficiency and energy mobility in the global south through the energy justice framework’, *Energy Policy*, 119. Available at: https://doi.org/10.1016/j.enpol.2018.04.026.

Mosner-Ansong, K.F. *et al.* (2024) ‘Energy efficiency awareness and assertiveness in Sub-Saharan Africa households: The case of Ghana’, *Energy for Sustainable Development*, 79, p. 101415. Available at: https://doi.org/10.1016/j.esd.2024.101415.

Moss, T. *et al.* (2020) *The Modern Energy Minimum: The case for a new global electricity consumption threshold*. Available at: https://energyforgrowth.org/wp-content/uploads/2019/01/FULL-Modern-Energy-Minimum-final-Jan2021.pdf (Accessed: 27 June 2023).

Munro, P., van der Horst, G. and Healy, S. (2017) ‘Energy justice for all? Rethinking Sustainable Development Goal 7 through struggles over traditional energy practices in Sierra Leone’, *Energy Policy* [Preprint]. Available at: https://doi.org/10.1016/j.enpol.2017.01.038.

Musonye, X.S. *et al.* (2020) ‘Integrated energy systems’ modeling studies for sub-Saharan Africa: A scoping review’, *Renewable and Sustainable Energy Reviews*, 128, p. 109915. Available at: https://doi.org/10.1016/j.rser.2020.109915.

Mutezo, G. and Mulopo, J. (2021) ‘A review of Africa’s transition from fossil fuels to renewable energy using circular economy principles’, *Renewable and Sustainable Energy Reviews*, 137, p. 110609. Available at: https://doi.org/10.1016/j.rser.2020.110609.

Mutiso, R. (2019) ‘How to bring affordable, Sustainable electricity to Africa’, *TEDSummit 2019* [Preprint]. Available at: https://www.ted.com/talks/rose_m_mutiso_how_to_bring_affordable_sustainable_electricity_to_africa?language=en (Accessed: 10 September 2020).

Mutiso, R. *et al.* (2022) *Who Decides Africa's Net Zero Pathways?* Available at: https://energyforgrowth.org/article/who-decides-africas-net-zero-pathways/ (Accessed: 31 July 2024).

Nana, J.Y. and Dioha, M.O. (2024) 'On the role of interconnected mini-grids in net-zero emissions electricity system: insights from Nigeria', *Environmental Research Letters*, 19(3), p. 034014. Available at: https://doi.org/10.1088/1748-9326/ad259f.

NCC (2022) *Nairobi City County Climate Action Plan C40*. Nairobi.

Newell, P. and Mulvaney, D. (2013) 'The political economy of the "just transition"', *The Geographical Journal*, 179(2), pp. 132–140. Available at: https://doi.org/10.1111/geoj.12008.

van Notten, P.W.F. *et al.* (2003) 'An updated scenario typology', *Futures*, 35(5), pp. 423–443. Available at: https://doi.org/10.1016/S0016-3287(02)00090-3.

Odhiambo, N.M. (2020) 'Financial development, income inequality and carbon emissions in sub-Saharan African countries: A panel data analysis', *Energy Exploration & Exploitation*, 38(5), pp. 1914–1931. Available at: https://doi.org/10.1177/0144598720941999.

Ogede, J.S. and Tiamiyu, H.O. (2022) 'Unveiling the Impact of Income Inequality on CO2 Emissions in Sub-Saharan Africa Countries (SSA)', *EuroEconomica*, 41(1).

Olawumi Israel-Akinbo, S., Snowball, J. and Fraser, G. (2018) 'An Investigation of Multidimensional Energy Poverty among South African Low-income Households', *South African Journal of Economics*, 86(4), pp. 468–487. Available at: https://doi.org/10.1111/saje.12207.

Olomi, D., Charles, G. and Juma, N. (2018) 'An inclusive approach to regulating the second economy: A tale of four Sub-Saharan African economies', *Journal of Entrepreneurship in Emerging Economies*, 10(3). Available at: https://doi.org/10.1108/JEEE-08-2017-0056.

OPHI (2021) *Interlinkages Between Multidimensional Poverty and Electricity*.

Otlhogile, M. and Shirley, R. (2023) 'The evolving just transition: definitions, context, and practical insights for Africa', *Environmental Research: Infrastructure and Sustainability*, 3(1), p. 013001. Available at: https://doi.org/10.1088/2634-4505/ac9a69.

Ouedraogo, N.S. (2017) 'Africa energy future: Alternative scenarios and their implications for sustainable development strategies', *Energy Policy*, 106(March), pp. 457–471. Available at: https://doi.org/10.1016/j.enpol.2017.03.021.

Pachauri, S. (2014a) *Energy Inequality*. Available at: https://iiasa.ac.at/web/home/research/alg/energy-inequality.html#:~:text=Inequalities are usually discussed and,starker than inequalities in income. (Accessed: 20 August 2020).

Pachauri, S. (2014b) *Energy Inequality*. Available at: https://iiasa.ac.at/web/home/research/alg/energy-inequality.html#:~:text=Inequalities are usually discussed and,starker than inequalities in income. (Accessed: 20 August 2020).

Pachauri, S. and Spreng, D. (2011) 'Measuring and monitoring energy poverty', *Energy Policy*, 39(12), pp. 7497–7504. Available at: https://doi.org/10.1016/j.enpol.2011.07.008.

Pachauri, S. and Spreng, D. (2012) ‘Towards an Integrative Framework for Energy Transitions of Households in Developing Countries’, in. Available at: https://doi.org/10.1007/978-94-007-2333-7_5.

Palermo, V., *et al.* (2018) *Guidebook: How to develop a Sustainable Energy Access and Climate Action Plan (SEACAP) in Sub-Saharan Africa*. Ispra.

Pandey, R. (2002) ‘Energy policy modelling: agenda for developing countries’, *Energy Policy*, 30(2), pp. 97–106. Available at: https://doi.org/10.1016/S0301-4215(01)00062-3.

Pappis, I. *et al.* (2019) *Energy projections for African countries*. Available at: https://doi.org/10.2760/678700.

Pasquini, L. (2020) ‘The urban governance of climate change adaptation in least-developed African countries and in small cities: the engagement of local decision-makers in Dar es Salaam, Tanzania, and Karonga, Malawi’, *Climate and Development*, 12(5), pp. 408–419. Available at: https://doi.org/10.1080/17565529.2019.1632166.

Patton, C. V., Sawicki, D.S. and Clark, J.J. (2015) *Basic methods of policy analysis and planning*, *Basic Methods of Policy Analysis and Planning*. Available at: https://doi.org/10.4324/9781315664736.

Pettigrew, A.M., Woodman, R.W. and Cameron, K.S. (2001) ‘STUDYING ORGANIZATIONAL CHANGE AND DEVELOPMENT: CHALLENGES FOR FUTURE RESEARCH.’, *Academy of Management Journal*, 44(4), pp. 697–713. Available at: https://doi.org/10.2307/3069411.

Popp, J. *et al.* (2021) ‘Bioeconomy: Biomass and biomass-based energy supply and demand’, *New Biotechnology*, 60, pp. 76–84. Available at: https://doi.org/10.1016/j.nbt.2020.10.004.

Puzzolo, E. *et al.* (2019) ‘Supply Considerations for Scaling Up Clean Cooking Fuels for Household Energy in Low- and Middle-Income Countries’, *GeoHealth*, 3(12), pp. 370–390. Available at: https://doi.org/10.1029/2019GH000208.

Raskin, P. *et al.* (2002) *Great Transition: The Promise and Lure of the Times Ahead*. Boston. Available at: https://gsg.org/publications.html#/ (Accessed: 30 December 2024).

REN21 (2021) *Renewables in Cities 2021 Global Status Report*. Paris: REN21 Secretariat. Available at: https://www.ren21.net/wp-content/uploads/2019/05/REC_2021_full-report_en.pdf.

Richard, O.O. (2012) ‘Energy consumption and economic growth in sub-Saharan Africa: An asymmetric cointegration analysis’, *International Economics*, 129, pp. 99–118. Available at: https://doi.org/10.1016/S2110-7017(13)60050-5.

Rockefeller Foundation (2024) *The Green Power Gap: Achieving an Energy Abundant Future for Everyone*. Available at: https://www.rockefellerfoundation.org/wp-content/uploads/2024/08/The-Green-Power-Gap-Achieving-an-Energy-Abundant-Future-for-Everyone-report-08012024.pdf (Accessed: 21 September 2024).

Ronnie, D., Lochner, M. and Etienne, N. (2019) ‘Secondary Cities in South Africa’, in R. Massey and A. Gunter (eds) *Urban Geography in South Africa*. Springer, Cham, pp. 121–137. Available at: https://doi.org/https://doi.org/10.1007/978-3-030-25369-1_8.

Sachiko Graber, B. *et al.* (2020) *UNDER THE GRID IMPROVING THE ECONOMICS AND RELIABILITY OF RURAL ELECTRICITY SERVICE WITH UNDERGRID MINIGRIDS CONTRIBUTORS SUGGESTED CITATION*. Available at: www.rmi.org/insight/under-the-grid/.

Saghir, J. and Santoro, J. (2018) *Urbanization in Sub-Saharan Africa: Meeting Challenges by Bridging Stakeholders*. Available at: https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/180411_Saghir_UrbanizationAfrica_Web.pdf.

Said, R. and Acheampong, A.O. (2023) 'Financial inclusion and energy poverty reduction in sub-Saharan Africa', *Utilities Policy*, 82, p. 101567. Available at: https://doi.org/10.1016/j.jup.2023.101567.

SAMSET (2014) *Supporting African Municipalities in Sustainable Energy Transitions*. Available at: https://samsetproject.net/.

SEA (2007) *Cape Town: State of Energy and Energy Futures Report*. Available at: http://www.cityenergy.org.za/uploads/resource_45.pdf.

SEA (2015a) *City-wide mitigation potential for South Africa*. Cape Town. Available at: http://www.cityenergy.org.za/uploads/resource_366.pdf.

SEA (2015b) *Modelling the Urban Energy Future of Sub-Saharan Africa*. Available at: http://samsetproject.net/wp-content/uploads/2016/02/Merged-Modelling-Urban-Energy-Futures.pdf.

SEA (2015c) *State of Energy in South African Cities*. Cape Town. Available at: https://www.sustainable.org.za/uploads/files/file80.pdf.

SEA (2019a) *Data and Scenario Modelling Technical Report, Tsévié City, Togo*. Cape Town.

SEA (2019b) *Data and Scenario Modelling Technical Report, Tsévié City, Togo*. Cape Town.

SEA (2019c) *Rapport technique sur la modélisation des scénarios pour la Commune d'Arrondissement de Yaoundé IV, Cameroun*. Cape Town.

SEA (2019d) *Rapport technique sur la modélisation des scénarios pour la Commune d'Arrondissement de Yaoundé IV, Cameroun*. Cape Town.

SEA (2020a) *Nairobi Pathways Modeling Report*. Cape Town.

SEA (2020b) *State of Energy in South African Cities Report 2020*. Cape Town.

SEA and CoCT (2015) *Cape Town State of Energy 2015 report*. Cape Town. Available at: https://africancityenergy.org/uploads/resource_22.pdf.

SEI (2024) *LEAP: Low Emissions Analysis Platform*. Available at: https://www.sei.org/tools/leap-long-range-energy-alternatives-planning-system/ (Accessed: 29 March 2024).

Sen, K.K. *et al.* (2024) 'Clarifying the linkage between renewable energy deployment and energy justice: Toward equitable sustainability', *Sustainable Futures*, 8, p. 100236. Available at: https://doi.org/10.1016/j.sftr.2024.100236.

Slavova, M. and Okwechime, E. (2016) 'African Smart Cities Strategies for Agenda 2063', *Africa Journal of Management*, 2(2). Available at: https://doi.org/10.1080/23322373.2016.1175266.

Soile, I. and Mu, X. (2015) ‘Who benefit most from fuel subsidies? Evidence from Nigeria’, *Energy Policy*, 87, pp. 314–324. Available at: https://doi.org/10.1016/j.enpol.2015.09.018.

Sokona, Y., Mulugetta, Y. and Gujba, H. (2012) ‘Widening energy access in Africa: Towards energy transition’, *Energy Policy* [Preprint]. Available at: https://doi.org/10.1016/j.enpol.2012.03.040.

Sola, A. *et al.* (2020) ‘Multi-domain urban-scale energy modelling tools: A review’, *Sustainable Cities and Society*, 54, p. 101872. Available at: https://doi.org/10.1016/j.scs.2019.101872.

Sovacool, B.K. (2012) ‘The political economy of energy poverty: A review of key challenges’, *Energy for Sustainable Development*, 16(3), pp. 272–282. Available at: https://doi.org/10.1016/j.esd.2012.05.006.

Sovacool, B.K. and Dworkin, M.H. (2014) *Global Energy Justice*. Cambridge University Press. Available at: https://doi.org/10.1017/CBO9781107323605.

Stats SA (2023) *Census 2022*. Available at: https://census.statssa.gov.za/assets/documents/2022/P03014_Census_2022_Statistical_Release.pdf (Accessed: 23 November 2024).

Stevis, D. and Felli, R. (2015) ‘Global labour unions and just transition to a green economy’, *International Environmental Agreements: Politics, Law and Economics*, 15(1), pp. 29–43. Available at: https://doi.org/10.1007/s10784-014-9266-1.

Streimikiene, D. *et al.* (2021) ‘Energy Poverty and Low Carbon Just Energy Transition: Comparative Study in Lithuania and Greece’, *Social Indicators Research*, 158(1), pp. 319–371. Available at: https://doi.org/10.1007/s11205-021-02685-9.

Szulecki, K. (2018) ‘Conceptualizing energy democracy’, *Environmental Politics*, 27(1), pp. 21–41. Available at: https://doi.org/10.1080/09644016.2017.1387294.

Tait, L. and Euston-Brown, M. (2017) ‘What role can African cities play in low-carbon development? A multilevel governance perspective of Ghana, Uganda and South Africa’, *Journal of Energy in Southern Africa*, 28(3), pp. 43–53. Available at: https://doi.org/10.17159/2413-3051/2017/v28i3a1959.

Tait, L., Mccall, B. and Stone, A. (2014) *Energy futures modelling for African cities: selecting a modelling tool for the SAMSET project*. Cape Town. Available at: https://open.uct.ac.za/items/7c59e14a-4def-459a-a2f1-9c6502f57183 (Accessed: 16 April 2024).

Taylor, M. (2020) *Energy subsidies: Evolution in the global energy transformation to 2050*. Abu Dhabi.

Tenenbaum, B., Greacen, C. and Shrestha, A. (2024) *Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India*. Available at: https://www.esmap.org/Mini-Grid-Solutions-for-Underserved-Customers (Accessed: 30 July 2024).

Tetteh, N. and Amponsah, O. (2020) ‘Sustainable adoption of smart homes from the Sub-Saharan African perspective’, *Sustainable Cities and Society*, 63, p. 102434. Available at: https://doi.org/10.1016/j.scs.2020.102434.

Todd Moss and Jacob Kincer (2023) *How does energy impact economic growth? An overview of the evidence*.

Toman, M.A. and Jemelkova, B. (2003) 'Energy and Economic Development: An Assessment of the State of Knowledge', *Energy Journal* [Preprint]. Available at: https://doi.org/10.5547/ISSN0195-6574-EJ-Vol24-No4-5.

UNDESA (2024) *World Population Prospects 2024*. Available at: https://www.un.org/development/desa/pd/world-population-prospects-2024 (Accessed: 11 September 2024).

UNDP (2021) *Poverty index reveals stark inequalities among ethnic groups*.

United Nations (2018a) *World Urban Prospects: The 2018 Revision - Key Facts*, *World Urbanization Prospects: The 2018 Revision*.

United Nations (2018b) *World Urbanization Prospects*, *Demographic Research*. Available at: https://doi.org/10.4054/demres.2005.12.9.

Uzar, U. (2020) 'Is income inequality a driver for renewable energy consumption?', *Journal of Cleaner Production*, 255, p. 120287. Available at: https://doi.org/10.1016/j.jclepro.2020.120287.

Vanegas Cantarero, M.M. (2020) 'Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries', *Energy Research & Social Science*, 70, p. 101716. Available at: https://doi.org/10.1016/j.erss.2020.101716.

van Veelen, B. and van der Horst, D. (2018) 'What is energy democracy? Connecting social science energy research and political theory', *Energy Research & Social Science*, 46, pp. 19–28. Available at: https://doi.org/10.1016/j.erss.2018.06.010.

van Vuuren, D.P. *et al.* (2014) 'A new scenario framework for Climate Change Research: scenario matrix architecture', *Climatic Change*, 122(3), pp. 373–386. Available at: https://doi.org/10.1007/s10584-013-0906-1.

Wahlund, M. and Palm, J. (2022) 'The role of energy democracy and energy citizenship for participatory energy transitions: A comprehensive review', *Energy Research & Social Science*, 87, p. 102482. Available at: https://doi.org/10.1016/j.erss.2021.102482.

Wallsgrove, R. *et al.* (2021) 'The Emerging Potential of Microgrids in the Transition to 100% Renewable Energy Systems', *Energies*, 14(6), p. 1687. Available at: https://doi.org/10.3390/en14061687.

Waud, A. (2018) *The Urban Heart of a Just Transition: How Cities Plan for Social Justice in Climate Action*, *Métropolitiques*. Available at: https://metropolitiques.eu/The-Urban-Heart-of-a-Just-Transition-How-Cities-Plan-for-Social-Justice-in.html (Accessed: 11 January 2025).

WEF (2019) *Ending global energy poverty - how can we do better?tle*. Available at: https://www.weforum.org/agenda/2019/11/energy-poverty-africa-sdg7/ (Accessed: 15 August 2020).

Winkler, H. *et al.* (2006) 'Policies and scenarios for Cape Town's energy future: Options for sustainable city energy development', *Journal of Energy in Southern Africa*, 17(1), pp. 28–41. Available at: https://doi.org/10.17159/2413-3051/2006/v17i1a3367.

Winkler, H. (2018) ‘Reducing inequality and carbon emissions: Innovation of developmental pathways’, *South African Journal of Science*, 114(11/12). Available at: https://doi.org/10.17159/sajs.2018/a0294.

World Bank (2016) *Global emissions per capita*, *World Bank Data*. Available at: https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?locations=ZG (Accessed: 29 September 2020).

World Bank (2019a) *GDP per capita (current US$) - Sub-Saharan Africa*, *World Bank Data*. Available at: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=ZG (Accessed: 10 October 2020).

World Bank (2019b) *GDP per capita (current US$) - World*, *World Bank Data*. Available at: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=1W (Accessed: 10 October 2020).

World Bank (2019c) *GDP per capita (current US$) - World*, *World Bank Data*. Available at: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=1W (Accessed: 10 October 2020).

Ye, Y., Koch, S.F. and Zhang, J. (2018) ‘Determinants of household electricity consumption in South Africa’, *Energy Economics* [Preprint]. Available at: https://doi.org/10.1016/j.eneco.2018.08.005.

Yongoua Nana, J. (2021) *What will the ‘Just Energy Transition’ mean for African cities? A Kampala case study*, *Energy for Growth Hub*. Available at: https://energyforgrowth.org/article/what-will-the-just-energy-transition-mean-for-african-cities-a-kampala-case-study/ (Accessed: 13 February 2025).

Yongoua Nana, J., Sambou, S. and Nicholson, L. (2019a) *Rapport d’inventaire des émissions de gaz à effet de serre de la Ville de Dakar, 2016*. Cape Town.

Yongoua Nana, J., Sambou, S. and Nicholson, L. (2019b) *Rapport d’inventaire des émissions de gaz à effet de serre de la Ville de Dakar, 2016*. Cape Town.

Yongoua Nana, J., Winkler, H. and Von Blottnitz, H. (2022) ‘Driving an Inclusive Transition to Electric Vehicle in African Cities: A Case Study of Dakar’, in *2022 IEEE PES/IAS PowerAfrica*. IEEE, pp. 1–5. Available at: https://doi.org/10.1109/PowerAfrica53997.2022.9905244.

Zerbo, E. (2017) ‘Energy consumption and economic growth in Sub-Saharan African countries: Further evidence’, *Economics Bulletin*, 37(3), pp. 1720–1744.

Zheng, M. *et al.* (2008) ‘Using Lorenz Curve and Gini Coefficient to Reflect the Inequality Degree of S&T Publications: An Examination of the Institutional Distribution of Publications in China and other Countries’, in. Available at: http://creativecommons.org/licenses/by/2.0/1.