Chapter

The Electrification-Appliance Uptake Gap: Assessing the Off-Grid Appliance Market in Rwanda Using the Multi-Tier Framework

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Abstract

The structure of the electricity system includes universal access to electricity that is adequate, available, reliable, affordable, legal, convenient, healthy, and safe and the efficient (inefficient) use of the electricity. Quality of access also influences clean energy technologies and electrical appliance purchase, ownership, use and perceived value (uptake, hereafter). Also, improved uptake assists in closing systemic gaps between rural and urban areas and grid and off-grid communities. Rwanda is projected to attain full electrification by 2024 (inclusive of all sectors: consumptive, productive and services). In this context, the East African country has articulated support mechanisms for off-grid market players through technical assessments and siting incentives. However, studies that focus on characterising diffusion and uptake of clean energy technologies and electrical appliances in mini-grid sites (market) are crucial to understand the emerging trends in off-grid rural electrification. This chapter contributes to this emerging discourse by proposing a four-fold demand side characterisation approach which (i) conducts a systemic review of literature to identify emerging off-grid themes as they relate to the multi-tier framework (MTF) and vice-versa, (ii) uses existing data to characterise the off-grid market (based on a typical village load), (iii) demonstrates the tariff regime changes using two payment methodologies (willingness to pay (WTP) and ability to pay (ATP)) and (iv) projects the 2024–2032 consumptive energy demand (using a simplified relation between appliance, it's rating and duration of use). Results of this characterisation demonstrate global and local level (glo-cal) literature gaps meriting a localised MTF assessment. The purpose of the localised assessment reported in this Chapter was therefore to understand appliance uptake gaps at the user level. The typical village load is basic (implying low energy demand). Ceteris paribus, higher WTP and ATP by users yield higher tariffs. However, a high ATP is a business sustainability determinant than a high WTP. Because energy consumption is also dependent on how efficiently it is used by those with access, the Chapter discusses appliance efficiency as a partial definition of sustainable energy and also as an example of sustainable energy. Then, demand stimulation pathways addressing wider systemic opportunities at the intersection of the theory of change and the theory of agency and risk reduction in markets, investments and policy (derisking markets, investments and policy) are discussed. The first pathway focuses on women and youth participation in productive use activities. The second pathway highlights strategies for appliance financing such as cost-sharing and micro-credit. The final pathway considers economic activity stimulation which has multiplier effects on energy demand and consequently energy-using appliances uptake. The implications for Sustainable Citizens and markets, investments and policy innovations are contextualised in the Sustainable Energy Utility business model.

Keywords: gender, consumer behaviour, time-using appliances, time-saving appliances, off-grid households, energy access, technological innovations, consumer choice, energy efficiency, appliance efficiency, derisking innovations, markets and investments, sustainable energy utility (SEU) model, transitioning economies

1. Introduction

Off-grid energy solutions often fail due to demand side factors such as insufficient energy consumption and low uptake of energy using appliances [1]. Anticipating community energy use as development occurs and users make clean energy and electrical appliance choices is crucial for national energy planning.

For example, the multi-tier definition of electrification goes beyond access and considers the quality of energy being accessed: adequacy, availability, reliability, quality, legality, convenience, health and safety (in households, productive engagements and communities) [2]. Today, issues at the intersection of community energy use, appliance uptake, the multi-tier context and their implications for Agenda 2030 for Sustainable Development Goals (SDGs) have not received adequate attention in research literature. This is also the case for the cluster of interdependent goals addressing well-being[1] (example relevant SDGs: Goal 1 on 'Zero Poverty', Goal 5 on 'Gender Equality', Goal 6 on 'Clean Water and Energy Access', Goal 7 on 'Energy Access for All', Goal 16 on 'Peace, Justice and Strong Institutions' and Goal 17 on 'Partnerships for the Goals'). This emerging discourse contributes to energy transitions and sustainability planning in transitioning economies. The purpose of this Chapter is to provide a localised and demand side characterisation approach of diffusion and uptake of clean energy technologies and electrical appliances in mini-grid sites (market) in order to understand the emerging trends in off-grid rural electrification.

East Africa's Rwanda has articulated support mechanisms to off-grid market players, for instance, through technical assessments and siting incentives. The country is targeting 100% electrification for all its inhabitants by year 2024, of which 52% is expected from grid and 48% through off-grid connections [3]. Rwanda is also considering a variety of off-grid energy options to complement electrification targets. According to the theory of change [1], the next step after electrification is adoption of electrical appliances[2]. However, this has not always

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[1] This is also the case with other sets of interdependent SDGs for example: those ending hunger and achieving food and nutrition security (example relevant SDGs: 2, 3, 5, 17), protecting the planet and building resilience (example relevant SDGs: 5, 12, 13, 14, 15, 17), ensuring access to sustainable energy and transport (example relevant SDGs: 5, 7, 11, 12, 17), sharing economic benefits and ensuring safety of society (example relevant SDGs: 7, 8, 10, 12, 17) and prioritising resources for local action and to accelerate implementation (example of relevant SDGs: 5, 9, 11, 17).

[2] The authors highlight that appliance uptake usually begins with lights and other typically bought household goods such as televisions, radios and mobile phones. Firms could buy machinery and refrigeration. Health centres can buy lighting or simple appliances for diagnosis and treatment. Schools may uptake appliances for evening classes.

been the case as other micro level determinants such as affordability of use [4] or the quality of service [5] influence adoption. I use the theory of agency[3] to understand the supplier-customer interface influencing uptake. Today, four factors are identified as requiring further analysis in clean energy technologies and electrical appliance uptake in Rwanda; firstly, uptake is urban centric, there is need for a rural energy use boost [7]. Electrified rural households continue to use basic appliances for lighting, phone charging and small cottage industries and humbly televisions (TVs), irons, fans, refrigerators, electric cooking stoves among others [1, 2, 7–11]. Secondly, appliance uptake differs across household classes [3, 7, 10, 12, 13]. Promotion of use across household classes is imperative. Thirdly, appliance uptake is gendered [3, 7, 8, 14]. Electric appliances that appeal to men and women may promote usage. Lastly, there are sectoral differences in energy use. It is important to forge inter-sectoral linkages for electrical appliance use.

Based on the foregoing, I argue that a localised Multi-Tier Framework (MTF) assessment is crucial to contextualise appliance insufficiency or the availability of energy inefficient appliances [9]. It underscores appliance needs in existing and newly created customer regions and relevant demand stimulation packages. It demonstrates appliances of value/benefit to improving well-being [15]. It highlights the Sustainable Citizen needs which may be more advanced than those of the customer/consumer. The possibilities of a Sustainable Energy Utility (SEU) model and policy innovations [16, 17]. The rest of this Chapter is structured as follows: in the next immediate sections. I discuss the MTF framework, global trends and local relevance. This is followed by the conceptual framework, methodology, results, discussion of findings, policy implications and conclusion.

2. The MTF

The multi-tier context has seven key check-points that can assist in carrying a localised assessment [2] (**Table 1**).

- The ability to power appliances (adequacy/capacity)

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Capacity	No electricity	1-50 W	50-500 W	500-2000 W	>2000 W	
Duration	< 4 hrs	4-8 hrs		8–16 hrs	16-22 hrs	22 hrs
Reliability	Unscheduled outages				No scheduled outages	
Quality	Low quality			Good quality		
Affordability	Not affordable		Affordable			
Legality	Not legal			Legal		
Health and Safety	Not convenient				Convenient	

Source: Ref: [2, 18].

Table 1.
MTF of household electricity.

[3] The theory of agency in marketing was underscored by early Scholars like Bergen et al., [6]. It has been applied in different contexts to explain different kinds of agency relationships. In this Chapter it focuses on the supplier-customer relationship.

- Number of day or night hours (duration)
- Reliability (electricity events and power outages)
- Whether voltage hours affect the use of desired appliances (voltage problems)
- The cost of a standard consumption (affordability- basic services less than 5% of household income)
- Whether the service is provided legally (legality)
- Absence of risk (health and safety)

In this Chapter, uptake refers to any or all of these demand side factors: acquiring (purchase, borrowing or gifting), number in built environment (ownership), how they are used (use), how often they are used (number of hours), and the benefits derived from all of these factors (user perceived value).

In the Rwandan context, the anticipated 100% electrification target coincides with its ambition of becoming an upper middle income country by 2035, a high income country by 2050 and a provider of high technology services to the wider East Africa region. If energy use will grow more quickly for households coming out of poverty than for households further up the income distribution [19] I assume that electrical appliances diffusion and energy consumption imitates an S-Curve pattern consisting of three stages of development: early; exponential and saturation [20, 21]. But in the real world energy transitions are not linear [22]. The Chapter lays out potential considerations in the off-grid sector.

3. Global trends

While electrical appliance use is a key driver of electrification rates, it is only now beginning to draw attention in developing world literature as a sustainability driver, a policy enabler and a standalone research agenda. By not using appliances, electrification and appliance related benefits: business opportunity, food security, ability to acquire knowledge, time savings and productivity among others remain elusive. Evidence from recent studies in sub-Saharan Africa include Rwanda [7], urban Ghana [23] and rural Uganda [24]. Other relevant studies cover the developing world in general but from a macro-level perspective and for a different point in time [19], others have relevance in strategic direction but are from a past era and a global north focus [25, 26]. A discussion of appliance uptake from the global south perspective has been sufficiently addressed in my previous work from a social perspective also using a Rwandan case [7]. However, from the energy consumption perspective which is the focus in this Chapter, appliance ownership is one of the key variables. In modelling domestic end use/consumption and determining load profiles using statistical or regression [27–31], engineering [32–36] and neural networks (NNs) [37–39]. It is also important to explore strategies for promoting appliance use.

4. Localising global trends

Electrification in the MTF context, decentralisation and centralisation, domestic end-use/consumption, energy as a service and well-being are four literature themes, with a glo-cal gap. It is important for the localised assessment.

4.1 Electrification in the MTF

As discussed earlier, the traditional definition of electrification is a binary measure only focusing on connections or non-connections, access and non-access and haves and haves not. It has been extended to reflect multi-dimensional issues under the MTF. Electrification is multi-dimensional when it captures the ability to avail energy that is adequate, available when needed, reliable, of good quality, affordable, legal, convenient, healthy and safe for all required services [2]. This shift in focus ensures that energy services of value to consumptive, productive and service related needs are targeted [2, 7]. Rwanda has already adapted its national statistics to reflect the MTF definition[4] [3]. For example, the electrical appliance use gap is highest in Tier 0 (zero distribution of appliances for 60.6 distribution of households across aggregated Tier- rural areas). Additionally, these households are in Ubudehe categories 1 and 2 and Social Classes 1 and 2 (**Tables 2–4**).

Though the MTF has been criticised for being complex to track at the global level and descriptive for acceptance at the national level [42], it has been deployed in other ways to improve the electrification experience[5]. One study constructed a bottom-up load profile at the household level for each tier of electricity access as set by the MTF, and the experiment was successfully tested in Rwanda, showing scalability [43]. The authors demonstrate further the inevitability of the present day Solar Home System (SHS) to meet energy demands beyond Tier 2 level and hence

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Distribution of households across aggregated Tier (Urban)	4.7	0.3	0.5	6.5	1.9	5.4
Distribution of households across aggregated Tier (Rural)	60.6	7.4	0.8	6.2	2.2	3.4
Source: Adapted from NISR [40].						

Table 2.
Distribution of households across aggregated tier (urban/rural).

Appliance level	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Type of appliances	—	Radio	Radio with CD Player and Mobile Phone	Electric Fan, TV, Computer and Printer	Refrigerator/ Freezer	Cooker
Distribution of appliances across Tiers	0	83.3	11.7	0.8	0.2	4
Source: Ref: [40].						

Table 3.
Distribution of appliances.

[4] To this end, evidence from the Fifth Integrated Household Living Conditions Survey (EICV5) datasets show that the classic binary measure underestimates electrification rates by 8% (MTF, 35% and classic binary electrification rate, 27%) [40].

[5] While the MTF does not explicitly measure ownership of appliance, the implied ownership and usage of a set of typical appliances does play a significant role for dimensions such as peak power supply and activity levels used in establishing minimum daily energy supply threshholds [42].

Social class	Ubudehe category	Ubudehe explanation
Poor	Category 1	Families who do not own a house and can hardly afford basic needs
Low-income	Category 2	Those who have a dwelling of their own and or are able to rent one but rarely get full-time jobs
Medium-income	Category 3	Those who have a job and farmers who go beyond subsistence farming to produce a surplus that can be sold. The latter also includes those with small and medium enterprises who can provide employment to dozens of people
Wealthy	Category 4	Those who own large-scale businesses, individuals working with international organisations and industries as well as public servants

Source: Refs: [3, 7, 41].

Table 4.
Community categorisation (Ubudehe category and social class).

the need for sizing [43]. Using MTF interconnection of mini-grids and main-grids enhances reliability [9]. The energy poverty gap measured by supply and demand can also be explained through the MTF [9]. In the reference context, should supply be at the highest level of the tier, with a complementary low value measurement on consumption, there are two ways to explain the anomaly. One could be that there is an inability to pay and another is that there is low demand for high amounts. The latter case, concerns the unavailability of appliances or the availability of inefficient appliances. In this regard, a localised MTF assessment adopted in this study captures unavailable appliances and available inefficient appliances.

4.2 Decentralisation and centralisation

Electrification expansion in sub-Saharan Africa will happen through two main pathways; by expanding the existing grid and improving system efficiency to already existing customers; and by connecting new consumers through off-grid services. The binary measure of electrification from years 2000, 2005 and 2010 in comparison to year 2017 in sub-Saharan African countries in general shows improved electrification rates (see Appendix 1) [44]. However, rates continue to be low in rural areas compared to urban areas. Decentralisation of the grid through SHSs, mini-grids and other renewable energy based sources is receiving significant interest in remote and hard to reach areas which might never be reached through the grid or if the grid eventually reaches them it may be very costly and time-consuming. Around the 1930s, the United States of America (USA) was faced with a similar urban-rural electrification/appliance uptake gap. The Rural Electrification Administration (REA)'s strategies included travelling road shows (Electric Circus)-specifically designed to promote appliance uptake in rural farms[6]. The non-interest loan programme improved farm productivity in general [26] and an almost 100% electrification was achieved between 1930 and 1960 (a jump from 10%) and recorded both short-term and long-term growth [45]. To this end, resource constrained settings require targeted appliance uptake and energy demand stimulation packages suitable to both new and existing customers of which a localised MTF assessment adopted in this Chapter captures specific user needs.

[6] Between 1939 and 1941, representatives from the REA organised a carnivalesque roadshow designed to encourage families to purchase and use electrical appliances and other equipment in their homes and on their farms.

4.3 Energy as a service and the well-being context

Energy as a service is another important beyond electrification dimension focusing on well-being, for example, a recent study linked energy poverty, energy consumption, household level (patterns) and urban-rural development to the well-being context [15]. The authors describe this as the bottom-up perspective that includes the functions, services, benefits and values. Extending this, authors argue that benefits and values are regarded as qualitative indicators that depend on individual and cultural contexts. In the same context, mutual inference guides the relationship between values and benefits. For example, individual preferences and WTP are shaped by experiencing and by observation of the benefits derived from services. At the same time, existing values and moral stances influence how contributions to well-being are perceived. This is also the perceived value of appliances and electrification described in Uganda [24, 46–48]. Based on this observation, a localised MTF assessment described in this Chapter is crucial to capture well-being gaps and identification of functionalities and appliances of value to users.

4.4 Domestic end-use/electricity consumption

Domestic end-use electricity consumption has been characterised by technique (statistical/regression, engineering and NN methodologies, **Table 5**). According to McLoughlin et al. [49], statistical/regression models can be both bottom-up and top-down. They are bottom-up when data used is collected at an individual dwelling level. They are top-down when data is collected at an aggregate, for example, national energy statistics, and GDP and population figures. Statistical/regression models are useful when a large dataset exists as they are based on real data and give a good understanding of electricity consumption patterns. Engineering and NNs on the other hand, are bottom-up modelling approaches as they use data gathered at the dwelling level to infer relationships between electricity uses and dwelling and occupant characteristics. McLoughlin et al. [49], summarised that:

i. Statistical/Regression methods are costly to implement and sometimes suffer from multicolinearity between variables.

ii. Engineering models are the only methodology that can be used without any historical information on electrical use. However, they may be complex to implement and need to be validated.

iii. NNs can model complex input parameters and may provide accurate means of modelling, however, they can also suffer from multicolinearity.

In all the methodologies, appliance ownership is a key emergent variable of demand side characterisation. It is important that appliance uptake strategies receive adequate attention in literature and practice. A summary of key techniques from selected studies, see **Table 5** [27–39].

Further related works are summarised: Hamidi et al. [50], Diemuodeke et al. [51], Richardson et al. [52], Debnath et al. [53], Paatero and Lund [54], Cao et al. [55], Palensky and Dietrich [56], Firth et al. [57], Guerra-Santin et al. [58], Menezes et al. [59]. Hamidi et al. [50] proposed a generic approach to quantifying the level of responsiveness among domestic consumers, by deriving load appliances of target consumers. This approach benefits domestic consumers who have not yet benefited

Author	Methodology	Findings	Important metrics/data
STATISTICAL/ REGRESSION			
O'Doherty et al. (2008)	Papke-Wooldridge generalised linear model to infer a relationship between ***appliance ownership*** and electricity consumption	Explanatory variables that had a high significance for electricity consumption (dwelling characteristics, location, value and dwelling type as well as occupant characteristics; income, age, period of residency, social class and tenure type)	Used data from the Irish National Survey of Housing Quality (NSHQ) carried out in 2001–2002. The survey gathered information from a sample of over 40,000 householders on characteristics and problems of the dwelling, and on household members.
Parti and Parti (1980)	Conditional Demand Model (CDA)	A high significance of ***appliance ownership*** over electricity consumption patterns across a 24-hour period	Monthly electricity bills over a yearly period were regressed against appliance ownership figures and demographic variables such as household income and number of occupants to disaggregate electricity demand into 16 different end-uses
ENGINEERING			
Yao and Steemers (2005)	Dynamic software model to generate load profiles based on occupancy patterns, **appliance ownership** and ratings.	Categorised electricity consumption determinants based on two categories: behavioural and physical both of which are strongly related to dwelling occupancy patterns*.	A set of twelve monthly cross section regression analyses of the household demand for electricity was conducted
Widen and Wackelgard (2010)	Modelling framework for stochastic generation of time resolved data.	Authors found it an effective way to generate load profiles	Time-use data (.i.e. occupant's schedule of activities) as well as ***appliances*** holdings, ratings and day-distributions to produce electricity load profiles
Shimoda et al. (2004)	Simulation model (using all the households in Osaka city, Japan-divided into 460 types of dwellings)	Occupant's time-use, external temperature, **appliance efficiencies** and dwelling thermal characteristics significantly influenced the electricity consumption patterns per day	Modelled electricity consumption on an hourly basis for different dwelling and household characteristics
Capasso et al. (1994)	Modelled electricity consumption patterns at a 15 minute period,	Homeowner's occupancy patterns, as well as ***appliance ownership***, usage and ratings contributed to significantly constructing the load profile shapes	A model of electric residential use (Knowledge of its most relevant socioeconomic and demographic characteristics, unitary energy consumption and

Author	Methodology	Findings	Important metrics/data
			the load profiles of individual ***household appliances***; several probability functions, Monte Carlo extraction process and simulation)
NN			
Aydinalp et al. (2002)	Developed a NN	Modelling electricity consumption for ***domestic appliances***, lighting and space cooling in the home	NN methodology used in developing the appliances, lighting, and space-cooling component of the model, the accuracy of its predictions, and some sample results.
Aydinalp et al. (2004)	Extended Aydinalp et al., (2002) NN	Extended this work to develop NN models for space and domestic water heating	NN methodology extension
Aydinalp et al. (2008)	A comparison of NN conditional demand analysis and engineering approaches to modelling end-use energy consumption in the residential sector	Variables used in the NN model that influenced electricity consumption were ***appliance ownership*** and usage, income, dwelling type and household composition	NN methodology comparison

Behavioural determinants relate to decisions made on an hourly/daily/weekly basis regarding use of particular appliances. Physical determinants relate to fixed variables that do not change often or at all with time such as dwelling.
Source: Adapted from Ref: [49]; Additional Information from Systemic Review.

Table 5.
Approaches to modelling domestic electricity consumption.

from current systems. Diemuodeke et al. [51] employed a HOMER hybrid optimization software to determine the best solar energy system and recommended that it is efficient, cost effective, reliable, and environmentally friendly. Richardson et al. [52] used a domestic electricity demand model based on occupant time-use data, and noted that the model overlooked overnight demand; that people sometimes leave lights on while asleep or may use timers to run appliances. Cao et al. [55], used a two-stage budgeting framework and detailed micro-survey data to estimate energy demand system in urban China and found that poor households are sensitive to the price of coal and rich households are sensitive to the price of gasoline. Firth et al. [57] recorded five-minutely average whole house power consumption over 72 dwellings at five sites over 2 years and found an overall increase in electricity consumption attributable to a 10.2% increase in consumption of 'standby' appliances (televisions and consumer electronics) and a 4.7% increase in the consumption of 'active appliances' (lighting, kettles and electric showers). And that consumption of different energy user groups is low but high income users contribute to the overall increase in consumption.

A local level MTF assessment is crucial because users differ in their energy use behaviours and patterns. At the same time, appliances have different characterisations, depending on the study purpose or methodology in which they are being studied for. In Rwanda, Ugirimbabazi [12] applied the HOMER hybrid software to determine the best renewable based power system using a typical rural village load (the village load was adopted for further analysis and discussion from the appliance use perspective in this Chapter).

5. Conceptual framework

In this section, a characterisation of appliance uptake and energy consumption for transitioning economies is discussed with a specific contextualisation of the off-grid sector (low income and resource constrained settings). In transitioning studies, Wolfram et al. [19], found that:

- Economic growth will lead to large gains in residential sector energy use as households coming out of poverty purchase energy-using assets.
- Demand for electrical appliances will increase energy demand for rural dwellers who have yet to acquire even the most basic energy-using assets.
- Households coming out of poverty have much higher income elasticities of demand for energy-using assets.

The works of Bowden and Offer [25] and Wolfram et al. [19] use diffusion approaches to explain behavioural characteristics of appliance uptake. They inferred on the S-Curve to explain adoption of energy-using appliances through following their utility functions. Bowden and Offer [25] used the costs and benefits of discretionary time conceptual framework to explain why home entertainment (such as radio and TV) and kitchen machines (e.g. vacuum cleaners, washing machines and refrigerators) diffuse more quickly than others. They found diffusion of time-saving appliances as going ahead of income. As household income rise, consumers give time to their discretionary time. The authors defined time-saving goods as those reducing the time required to complete a specific task. Time-using goods are those which require the use of discretionary time, time which can be used according to the person's taste. Wolfram et al. [19] assessed cars and refrigerators diffusion across 28 countries in both the developed and the developing world by modelling the appliance or vehicle acquisition decision and adding features relevant to the developing world as follows:

> *The basic logic is straightforward. Households face a choice between consuming a divisible good with decreasing marginal utility (such as food) and an indivisible appliance that provides a fixed utility. As households' income increases, utility from increased consumption of the divisible good declines and, the probability that the household's utility from the appliance exceeds the utility from forgone food increases. Under reasonable assumptions on the distribution of appliance or vehicle valuations, this generates an S-shaped ownership curve* [19].

Appliance ownership is also low because most energy-using assets are expensive and most low-income households in the developing world are credit-constrained. A household does not make a period-by-period choice of whether to own an asset effectively by renting it, as is assumed in much of the developed-market literature. Instead the household must save to acquire the asset, which delays the asset acquisition to a higher income than would be suggested by the rental model.

DOI: http://dx.doi.org/10.5772/intechopen.93883

Because lower income households are less able to self-finance, this delay is bigger at lower income levels and the resulting S-curve becomes steeper. Also, if households are self-financing through savings growth in income, and not just current income, will affect the asset acquisition [19].

From this conceptual framework, S-curve assumptions guide the Chapter as follows: In the first stages of adoption (poor households and medium-income households) will likely not have enough money to buy appliances. There are few initial purchases. This is the period that coincides with initial stages of development under the S-Curve. In the second stage of adoption, households have saved to afford purchases or can borrow. There is an exponential growth in purchases. Where there is access to roads and electricity, purchases of cooling appliances like refrigerator will increase. Additionally, households will purchase energy efficient appliances, including electric cook stoves. Wealthy households may buy expensive electric cook stoves while poor and medium income households may buy inefficient (cheaper) electric appliances. I assume that this is the stage that will coincide with rural Rwandan consumers beyond 2024 and the SEU model which underscores sustainable citizenry is introduced in Section 8 to explain this future.

6. Methods and data

6.1 Data

As discussed earlier, a macro-level dataset (EICV5) with 14,580 households has adapted the MTF definition (Section 4) [40]. I use this dataset to demonstrate tier characterisation at the national level. I complement the national level characterisation with village load data [12]. The village load has 164 users (**Table 6**). While the village load may not be a direct replica of all the villages in Rwanda, it provides a good starting point for the MTF localisation discussion from the appliance uptake perspective. Having compared appliance ownership and diffusion patterns in the off-grid market [7, 40], the village load adopted is a reasonable proxy, the source is credible academic work [12]. Use of an existing load profile is also time and cost effective. Difficulty in administering surveys (energy use and consumption based) and the associated uncertainty is documented [20, 60]. Data on newly created households is obtained from the Population and Housing Census of Rwanda (2012) (**Table** 7) [61].

6.2 Methods

6.2.1 Scenario analyses using payment mechanisms (a, b, c)

Scenario analyses explore WTP and ATP for any associated tarrif regime. These payment mechanisms are adopted from earlier studies elsewhere to demonstrate the role of different amounts of willingness (**Table 8**).[7]

[7] The selected payment mechanisms used are adopted from other contexts to demonstrate changes on the tarrif regime as different amounts are adopted.

User Classification by Ugirimbabazi (2015)	Category	Number	User classification adopted in this chapter
Domestic purposes	Rich families	10	Consumptive Sector
	Medium income families	40	Consumptive Sector
	Low income families	100	Consumptive Sector
Industrial/Commercial/ Community Purposes	Shops and bars	5	Productive Sector
	Administration posts	2	Service Sector
	Medical center	1	Service Sector
	Primary school	1	Service Sector
	Secondary school	1	Service Sector
	Community church	1	Service Sector
	Small manufacturing units	3	Productive Sector
Total		**164**	

Source: Ref: [12].

Table 6.
Composition of users for the village load.

Projections year	Rural Population	Mean size	Total households	Newly households to be created
2024	10,446,563	3.6	2,896,273	86,518
2025	10,581,467	3.5	2,985,468	89,195
2026	10,714,117	3.5	3,077,416	91,948
2027	10,844,122	3.4	3,172,174	94,758
2028	10,970,613	3.4	3,269,664	97,490
2029	11,092,996	3.3	3,369,885	100,221
2030	11,210,972	3.2	3,472,931	103,045
2031	11,324,247	3.2	3,578,902	105,971
2032	11,432,529	3.1	3,687,913	109,011

Source: Ref: [61].

Table 7.
Evolution of the number and size of the private households and the newly created private households between 2024 and 2032 by area of residence according to the medium projections scenario (rural).

6.2.2 Scenario analysis using energy consumption and newly created households (scenario d)

6.2.2.1 Basic model of energy consumption

As discussed earlier, domestic use predictions using linear models and theories assume exponential growth once households have saved enough money and can start buying appliances and demand energy use. This is also the case for diffusion theories discussed earlier. This Chapter uses a simplified method to capture energy

DOI: http://dx.doi.org/10.5772/intechopen.93883

Scenario	Scenario a	Scenario b	Scenario c
What happens to the tarrif regime for different WTP and ATP (Scenario a, b and c)	WTP USD5.20/month	ATP USD 16.25/month	ATP USD 9/month
Data sources of the payment methodology (Scenario a, b and c)	*Ref:* [62]	*Ref:* [62]	*Ref:* [63]

Source: Ref: [62, 63].

Table 8.
Willingness and ability to buy.

demand (using a simplified relation between appliance, it's rating and duration of use) [64] as follows:

$$E_e = N_a \times A_r \times H_u \times P_n \tag{1}$$

Where:
E_e= energy use per appliance.
N_a= the number of appliances (of same kind).
A_r= the power rating of appliances in watts.
H_u= the duration of appliance usage (per day/365 days per year).
P_n= the number of households.

7. Results

7.1 Distribution of Rwandan households across Tier (National Level)

Tier 0 has the highest distribution of households across aggregated tier (**Table 9(a)**)
Distribution of households across capacity tier is also highest in Tier 0 (**Table 9(b)**)
Tier 5 has the highest distribution of households across duration tier-day time (**Table 9(c)**)
Distribution of households across duration tier-evening is highest in Tier 3 and Tier 5 (**Table 9(d)**)
Tier 5 has the highest distribution of households across reliability tier (**Table 9(e)**)
Distribution of households across quality tier is highest in Tier 5 (**Table 9(f)**)
All households meet the legality tier (**Table 9(g)**)
Tier 5 has the highest distribution of households across safety tier (**Table 9(h)**)

7.2 Village load

7.2.1 Appliance ownership

Appliance ownership is high for lighting appliances (lamps) and communication (cell phones and radio). Computers are common in the services sector (community church, secondary school, primary school, medical centre, administration post, shops and bars) (**Table 10**).

7.2.2 The village load and the multi-tier context

Based on the characterisation proposed in this study (consumptive, productive and services), the village load is distributable between Tier 2, 3 and 4. Thus there is

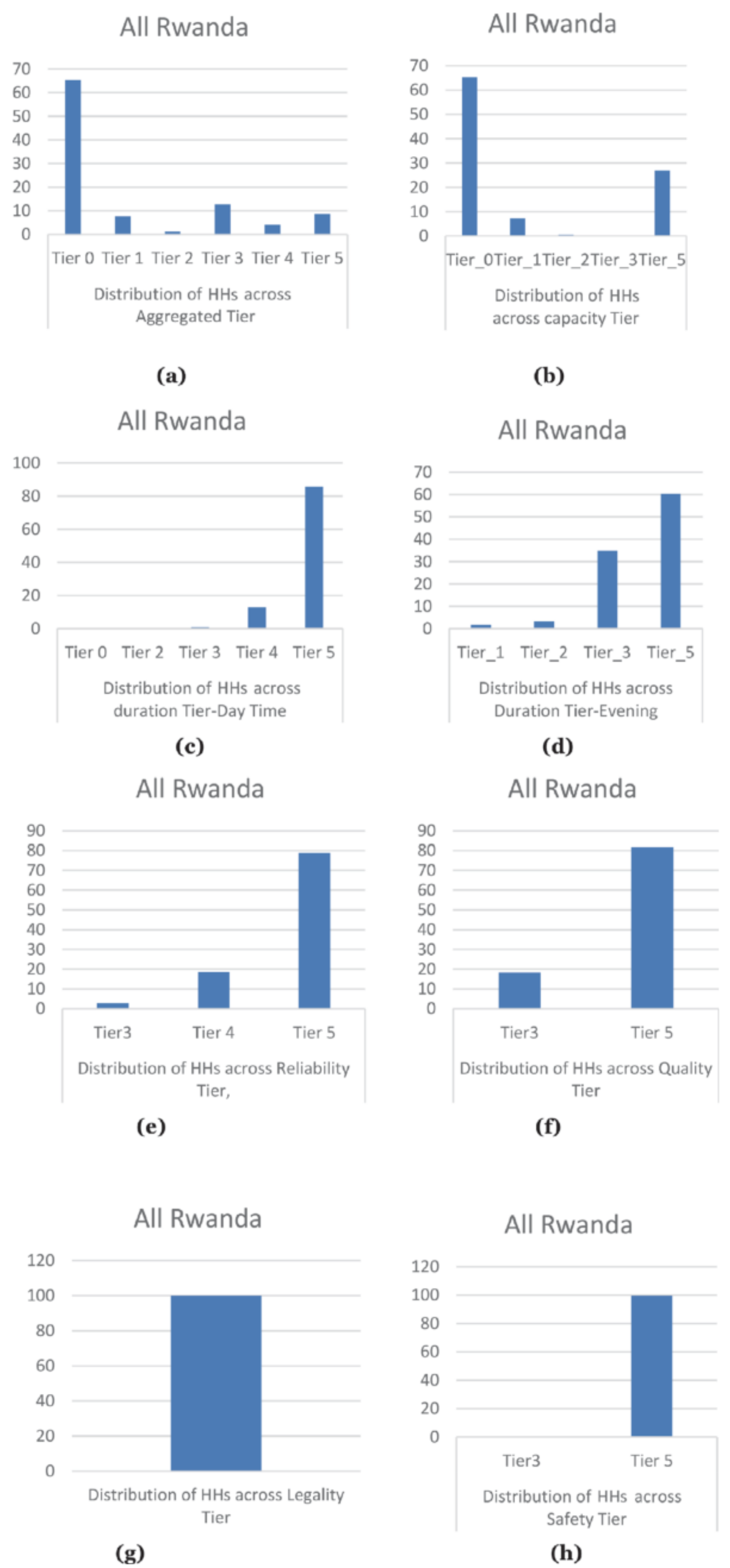

Table 9.
Distribution of Rwandan households across tiers (Source: Ref: [40]).

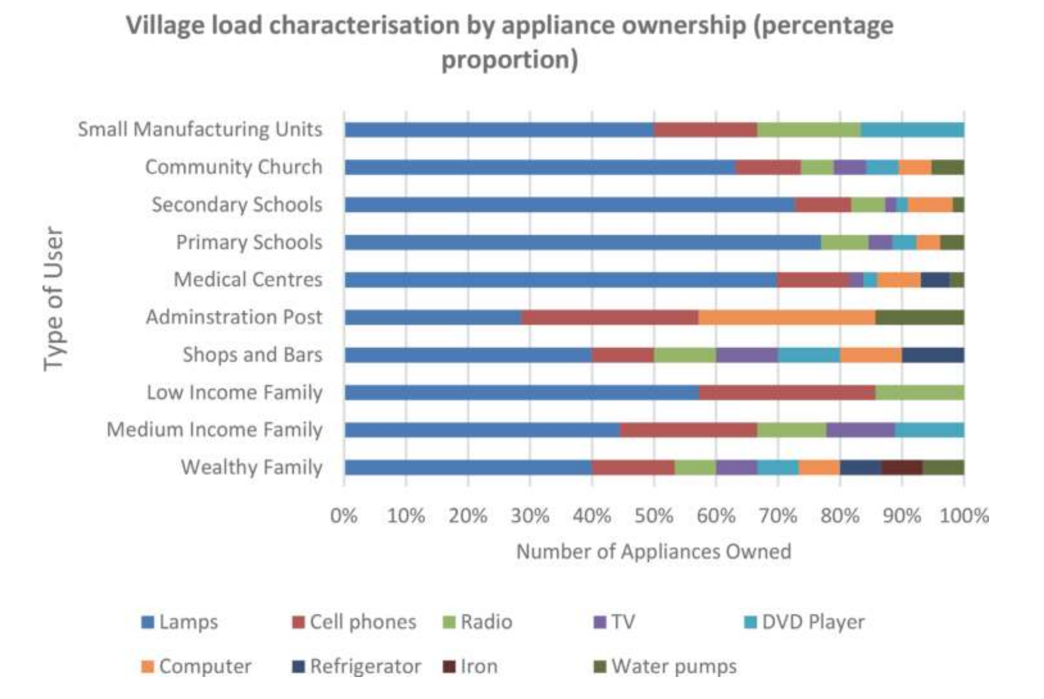

Table 10.
Characterising appliance ownership (percentage proportion) (Source: Ref: [12]).

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
	Not applicable	Radio	Radio with CD Player and Mobile Phone	Tier 2 AND Electric Fan, TV, Computer and Printer	Tier 3 AND Refrigerator Freezer	TIER 4 AND Cooker
Wealthy Households					10 Families (46 kWh)	
Medium Income Households				40 Families (32kWh)		
Low Income households			100 Families (39kWh)			
Shops and Bars					5 Shops and Bars (35kWh)	
Administrative Post				2 Administration Posts (3kWh)		
Medical Center					1 Medical Centre (34kWh)	
Primary Schools				1 Primary School (5kWh)		
Secondary Schools				I Secondary School (11kWh)		
Community Church				I Community Church (5kWh)		

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Small manufacturing units			3 Small Manufacturing units (49kWh)			
Total			88 kWh	56 kWh	115 kWh	

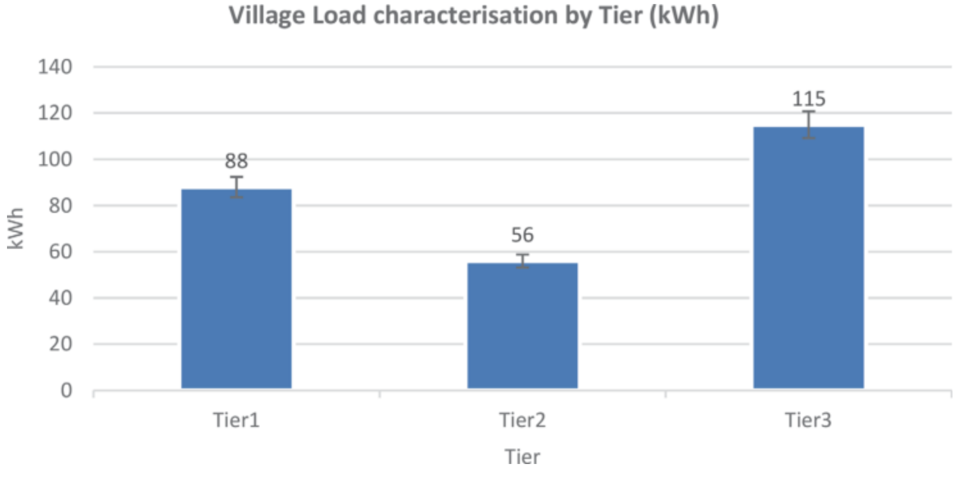

Table 11.
(a) Characterising village load; (b) characterising consumption by multi-tier context (kWh) (Source: Ref: [2, 12]).

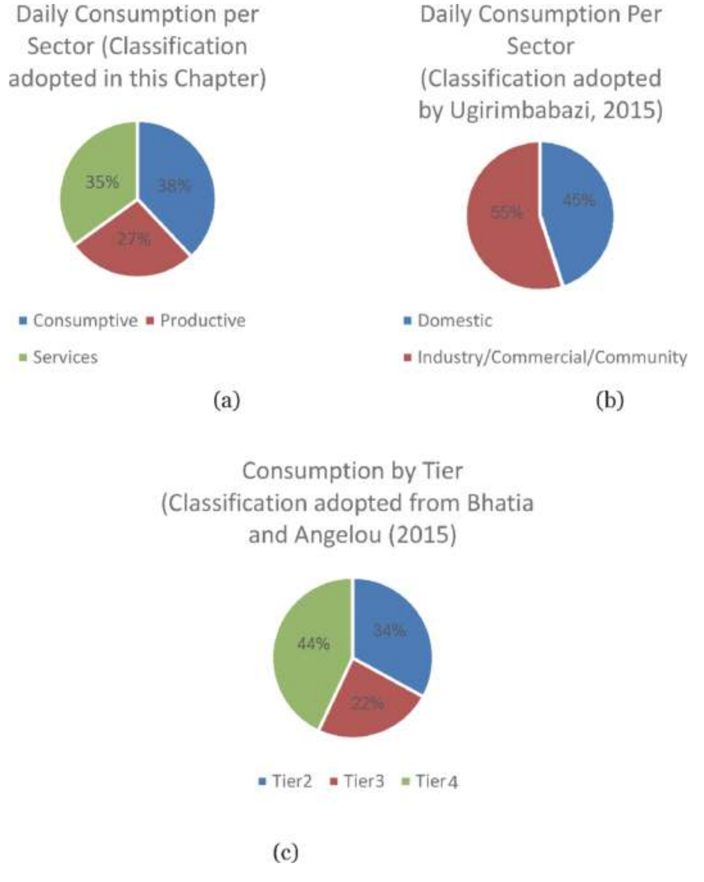

Table 12.
Characterising consumption by different classification (percentage) (Source: Ref: [2, 12]).

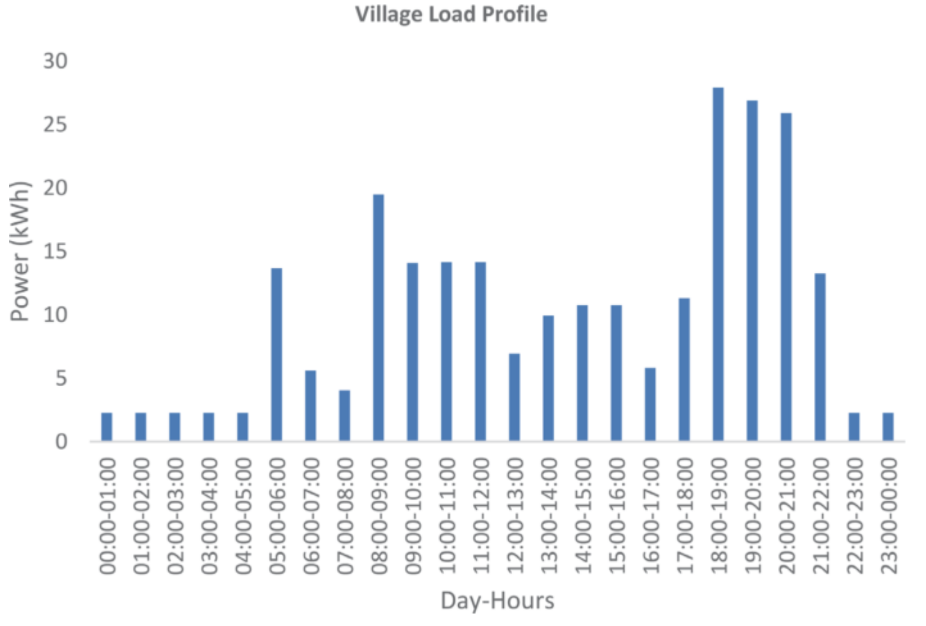

Table 13.
Hourly consumption (kWh) (Source: Ref: [12]).

no consumption for Tier 0 and Tier 5 (**Table 11**). Below we characterise total village consumption by different definitions such as (consumptive, productive and services adopted in this study 12(a)). The other characterisation is from the source document of the village load (12b) and the final one is the Tier approach. This section shows how definitional issues come to play in energy consumption, for example what is being counted and who is counting it. Also when was it counted [22] (**Table 12**).

7.2.3 Village load hourly consumption

The peak usage of energy is experienced between 19:00 and 22:00 hours and also between 09:00 and 12:00 hours (**Table 13**).

7.3 Scenario analyses (a-c)

Ceteris paribus, higher WTP and ATP by users yield higher tariffs. However, a high ATP is a business sustainability determinant than a high WTP (**Table 14**).

7.4 Scenario analysis (d)

7.4.1 Using daily consumption and newly created households

A further analysis of the household sector demonstrates that total energy use for the 2024–2032 period has an S-Curve pattern (Scenario d) (**Table 15**). It confirms Wolfram et al. findings of energy consumption behaviours of low income households coming out of poverty [19] and that as an economy grows its residential sector

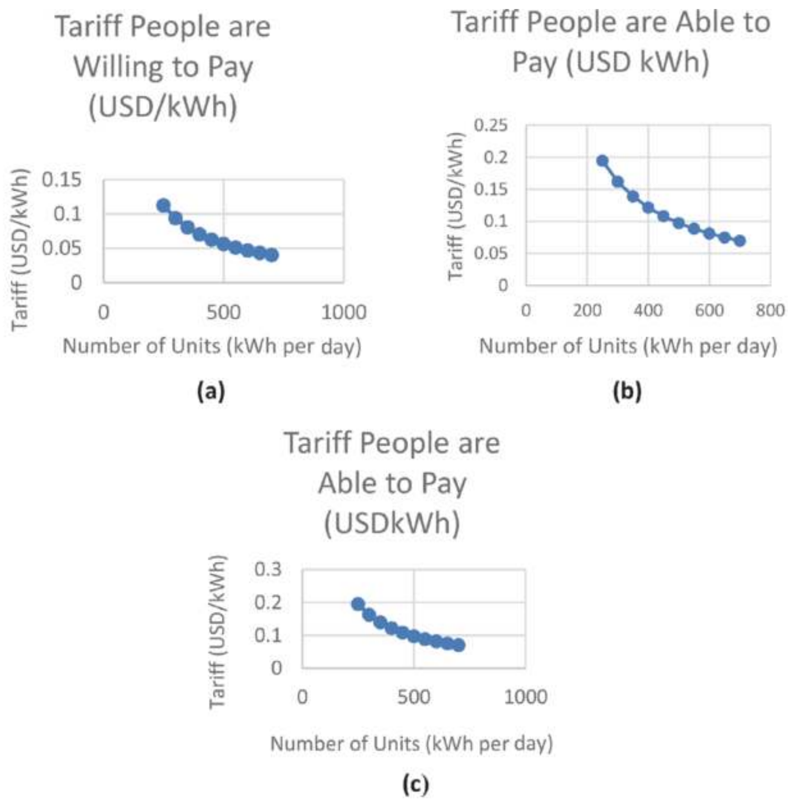

Table 14.
Tariff regimes and payment mechanisms (USD/kWh).

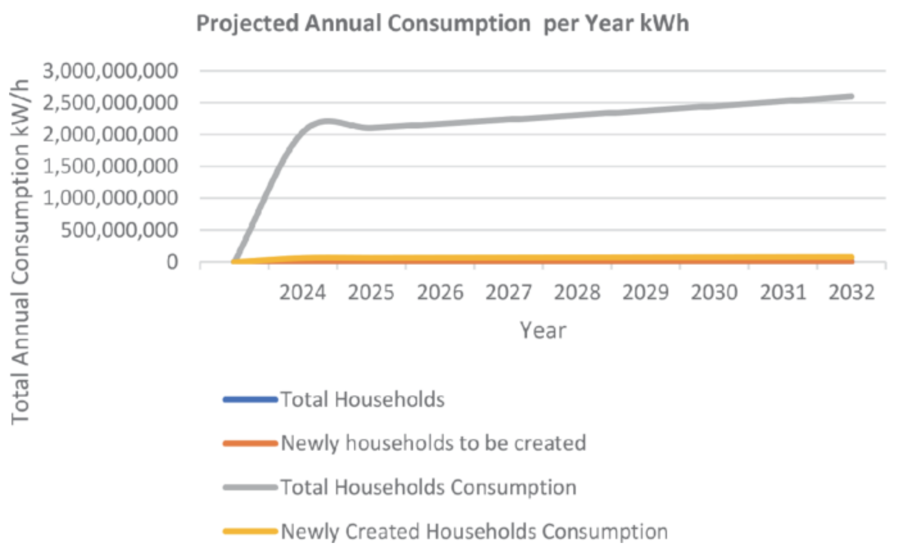

Table 15.
Scenario d (consumptive energy projection 2024–2032) (kWh/year) (Source: Author's Computations based on Ref: [12, 61]).

grows [21]. Energy consumption is heavily influenced by energy behaviours [66]. In Ghanaian urban households, high appliance ownership and usage is a key determinant of energy consumption [23].

8. Discussion and policy implications

8.1 Clean energy technologies and electrical appliances opportunities

As discussed earlier, insufficient energy consumption and appliance uptake deficiencies in the MTF context in this Chapter are discussed at the intersection of the theory of change and the theory of agency. In the case country, challenges include insufficient investments in energy infrastructures and the resultant energy crises (have negative effects on socio-economic development) [67]. Other constraints include (a) electricity demands almost equal with generation, with little reserves, (b) high petroleum products expenditures, (c) lack of investment, (d), government subsidies, which cushion electricity retail prices, and (e) inability to engage in much electricity export and trade because of relatively uncompetitive pricing regimes [68]. Rwanda's electricity price is about 22.2% more expensive than the highest tariff in the East African Region [68]. Moreover, high cost of electricity, generation capacity (demand and supply not aligned), insufficient resource margin and high system losses affect electrification prospects [69]. Feed-in-tariffs have been suggested until technologies are mature[8] [70].

Overally, external debt is reported as increasing electrification rates in the East African state [4]. Nonetheless, electrification rate reducers and increasers are distinguishable [4]. Rate increasers such as gross capital formation, external debt and agriculture. Rate reducers are multi-lateral debts and claims to central government. As per these conclusions by Mwizerwa and Bikorimana [4], I introduced the theory of change in this Chapter to underscore continued interventions by the Government of Rwanda (GoR) in reviving agriculture and promote women and youth inclusion (women and youth currently occupy 70% of the population). Improved outcomes of income and purchasing power may influence the capacity to buy electrical appliances. In another study conducted in Rwanda, connected households have more income compared to their matched unconnected counterparts [71]. To this end, electrification investments and feed-in-tariffs can cushion the negative transition effects and electricity utilisation strategies which should include complementary appliance use strategies to push forward off-grid electrification targets.

Related to the above discussion, the first pathway identified in this study, is participation of women and youth in productive use of energy technologies and appliances [26, 72]. As discussed earlier, agriculture as an electrification rate enabler (it is important that women and youth participation in productive use activities through the provision of energy and complementary energy-using appliances is promoted). Another study found appliance uptake to be highly gendered in Rwanda and the gender of the Head of Household (HoH) is a key driver in appliance uptake (from the Social Shaping of Technology perspective) [7]. At the same time, in terms of energy use, a study assessing productive use of electricity and street food in urban and peri-urban Rwanda found no significant difference between men and women (for all case study countries including Rwanda, Senegal and South Africa) [73]. However, Rwandan entrepreneurs had a preference for gas cookers and new appliances to attract customers to their businesses. In previous studies, specific differences in appliance uptake were found to be revolving around the use of discretionary time. For instance, time-using goods, are those which require the use of discretionary time in conjunction with the product [20]. Such trade-offs may be explained from the use of discretionary time perspective:

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[8] This is mainly recommended for solar and wind technologies diffusion from the climate change adaptation and mitigation perspective.

- Radio and TV are typically time-using goods. They enhance perceived quality.
- Time-saving goods reduce the time required to complete a specific household task. While they are applied to housework, they can increase the quantity of discretionary time.

The second pathway concerns financing of appliances. This is because, a high WTP for electricity is not translating to the ATP cost recovering prices even under extended time periods [71]. A contigent behaviour analysis study in Rwanda determining potential benefits of electricity to unconnected customers shows that even the remotest customers are willing to pay for electricity [74]. However, the same study demonstrates that amounts customers are willing to pay cannot cover the cost of electricity which undermines the financial viability of projects [74]. Additionally, electrification benefits remain for minor use activities such as lighting, phone charging and agriculture processing. In the developing world, energy-using assets are expensive and low-income households are credit-constrained [19].

The third and final pathway considers economic activity stimulation. Three energy trends [55] from literature point to sectoral trade-offs that accompany energy transitions at the macro-level: as industrial energy demand increases most rapidly at the initial stages of development, growth slows steadily throughout the industrialisation process. Second, energy demand for transportation rises steadily, and takes the majority share of total energy use at the later stages of development. Third and finally, energy demand originating from the residential and commercial sector also increases to surpass industrial demand, but long term growth is not as pronounced in the transport sector. In this case, intersectoral linkages between infrastructure and industrial development will stimulate energy and appliances demand.

Other researchers found weak evidence of electrification on classical poverty indicators [21] and high energy bills [10] in Rwanda. In terms of energy efficiency, trade-offs exist between appliance uptake and associated benefits. For instance, anticipated benefits in improved lighting can be outweighed by uptake of other appliances like television. Differences in the speed of diffusion between appliances has been observed elsewhere, for example, going back in time, evidence from Britain and the USA, illustrates that since the 1920s, some household appliances diffuse more rapidly than others [20]. Home entertainment appliances such as radio and TV have diffused much faster than household and kitchen machines such as refrigerators. Differences in adoption are suggested to be a trade-off between energy-efficiency and cost of purchasing household appliances decision. To increase appliance uptake, ownership and use beyond electrification, further studies may explore this area. Recently, Sovacool [22] demonstrates that transitions appear not as an exponential line on a graph, but as a 'punctuated equilibrium which dips and rises'.

The appliance market across the globe has been observed as a niche. To this end, the 2020 global projections for the off-grid appliances in general, shows that fans, televisions and refrigerators are most promising with potential to reach $4.7B per year [8]. In Rwanda, this is relatable given the low village load across user groups or tiers (**Table 11**). Also, differing load profiles mean that as households transition from being low income to medium income to wealthy demand for appliances may improve. Evidence elsewhere shows high demand responsiveness in wealthy households, for example, in the UK wealthy households have at least one appliance under each use group; cold appliances- refrigerator, lighting appliances-light; brown appliances- TVs and Radio and Miscellaneous-Iron [50]. Both medium income and low-income households, only have brown appliances and lighting appliances [50]. Class distinction in appliance ownership is also observable in Rwanda (as discussed earlier). However, the minor distinction between low-income and medium-income households in terms of appliance ownership is an indicator of market potential. A consumer transition to wealthy status in Rwanda may stimulate appliance demand and energy use. In this transition it would be interesting to discuss the energy efficiency transition choices and preferences by consumers and implications for sustainable energy.

The S-Curve pattern demonstrated in Section 5 and 6 confirms consumer behaviours from world demand projections by earlier researchers (for example, [19]). As estimates by one study show that by 2035, developing world demand will almost double developed world demand [19]. Such an economic transition, will also mean, a consumer transition, as developing world customers become developed world customers. As households rise out of poverty and enter middle class category, they purchase new assets many of which use substantial amount of energy, and they also become, first time purchasers of energy-using assets [19].

Finally, deployment of Internet of Things (IOT) in energy studies has received significant interest elsewhere but also in Rwanda to address information asymmetries in the energy market. Particularly the use of large datasets in understanding consumer behaviour in energy markets. Kennedy et al. [75], used a BBOX database with 68600SHS customers over 562 days to compare non-parametric clustering method together with customer segmentation with linear models. Results demonstrate that linear models may be misleading because women and those recruited by agent advertising or word of mouth were more likely in the company's core clientele. Yet, linear models suggested that they are less profitable customers [75]. While IOT use is more likely to provide detailed insights on consumer behaviour to upscale business models, Bisaga et al. [76] notes that data privacy remains crucial. My follow on empirical work will determine emerging energy cultures using the Energy Cultures Framework and ground theory techniques. This will also be complemented by other forth-coming papers investigating willingness to use energy-using assets and the perceived user values (using the User Perceived Value-UPV Games and Questionnaire administration) and the resultant policy issues.

8.2 Why appliance efficiency?

In this section I discuss the reasons of appliance efficiency from two angles: first as a partial definition for sustainable energy and second as a reason for sustainable energy.

8.2.1 Appliance efficiency as a partial definition for sustainable energy

Labels and standards are regarded as valuable tools in implementing national energy efficiency policy [65]. Energy efficiency standards set minimum energy perfomance requirements for products and classes of products [65]. Labels are designed to inform consumer choice at the time of purchase and include endorsements, certifications, product comparisons, and product energy usage [65]. These valuable tools may assist in the avoidance of costly strategies such as China's Beijing refrigerator mistake (which contributed to the terrible air during the Beijing Olympics) [65].

Global savings in terms of energy efficiency are reported in terms of reduced energy use and costs 3–4% per year in all places where they have been introduced even in nations where they had no previous efficiency standards or program [65] (**Table 16**).

Metric	Labels/standards
80 Nations	Have adopted some kind of efficiency and/or labelling
55 different product types	Covered by a mandatory standard
3600 different policy measures	Addressing perfomance standards, and various forms of labelling
75 Nations	Have refrigerator measures
73 Nations	Regulate air conditioning
76 Countries	Have lighting measures
47 Countries	Have measures for television efficiency
Sources: Ref: [65].	

Table 16.
Global progress on appliance efficiency standards and labels.

8.2.2 Appliance efficiency as an example of sustainable energy

Specific benefits from appliance labels and standards are observable at four levels (individual, sectoral, national and international) (**Box 1**) [65]:

1. Individual: household level co-benefits (improved health and well-being, poverty alleviation, improved energy affordability and access and increased disposable income)

2. Sectoral: Industrial, transport, residential, commercial level co-benefits (include increased productivity and competitiveness, improved energy and other infrastructure benefits, and increased profits and asset values)

3. National: job creation, reduced energy-related public expenditure, energy security and valuable macro-economic benefits

4. International: Moderating energy prices, reducing natural resource pressure, and promoting the achievement of development goals

In developing countries, where light is provided either by candle or kerosene, or, if electricity is available, by an inexpensive incandescent bulb, new LED light technology could provide light using only 1 watt of power, which could be generated by a small solar panel and backed up by ordinary rechargeable batteries; total costs: US$25. These are examples of the astounding efficiency opportunities, that can be remotely powered without having to construct power plants or transmission lines, and that will provide light where none was before, or will eliminate GHG from burning fossil fuels or biomass. These LEDs are 1000 times more efficient at generating light than fuel based light (candles or kerosene), produce no indoor pollution, and have the potential, if they replaced fuel-based lighting, to save the equivalent of about 1.3 million barrels of oil per day. That would be a savings, at US$45 per barrel oil*, of about US$58.5 million per day—over US$ 21,352.5 billion per year—mostly in the poorest nations in the world, and virtually all of this money would be used to import the fuel. Reinvesting these savings in other energy efficient technologies could multiply the savings, while simultaneously improving the lives of over a billion people. And, as an added benefit, it would eliminate the 190 million tons of CO2 released annually when the fuel is burned.

**Price per barrel oil is adjusted to the 2019–2020 average of USD45.00 to provide the current situation.*

Source: Ref: [65].

Box 1.
One thought experiment demonstrating co-benefits of appliance efficiency.

8.3 Changing the energy consumption paradigm: SEU model

As discussed earlier a localised MTF assessment (Section 4) is crucial in addressing energy consumption related challenges of the Tier approach (**Table 1**). Empirical evidence demonstrated technologies and appliance uptake gaps (Section 3 and 4). Based on developed and developing world transition examples, energy transitions need to be complemented by matching business models. Recent studies have extensively explored the pros, cons and alternatives of different business models [16, 17]. This Chapter focused on a localised solution. The SEU model has positive attributes [77–81]. It stresses energy efficiency and renewable energy services to residents, businesses and governments. Demand for energy services jobs, sustainable energy services, financial savings that can accrue from efficiency investments (rather than relying on system benefit charges placed on utility bills for revenue) and a shared savings model for financing bonds to finance programs (**Figure 1**).

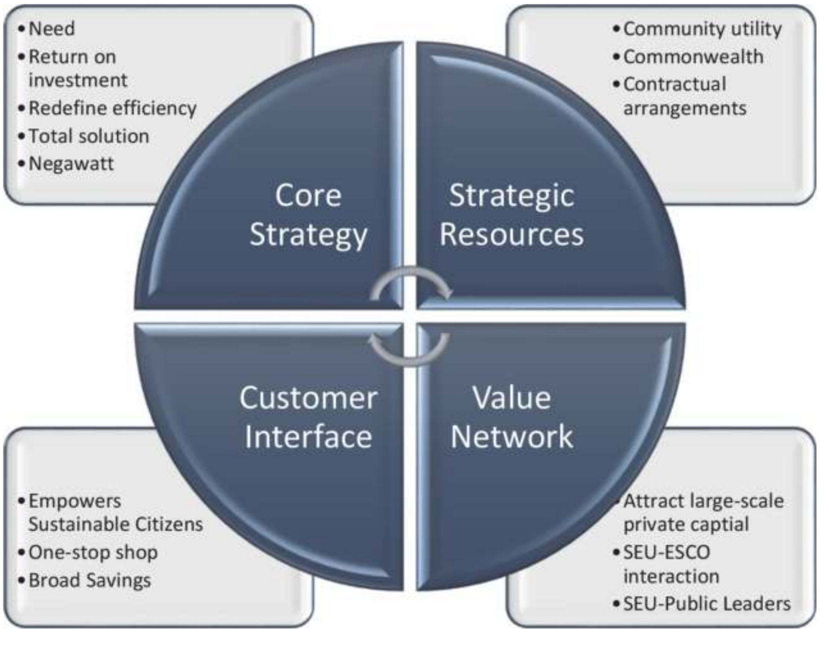


Figure 1.
The SEU model. Source: Ref: [17].

8.4 Policy implications and future work

This chapter demonstrated relevance of the utility of the bottom-up "polycentric" approach to off-grid rural electrification and its implications on the off-grid energy market in the developing world. Two theories: agency and change were used to assess the uptake of off-grid appliances in Rwanda, and the attendant direct relationship to clean energy investments and off-grid policy development. This is crucial given the relevance of both the MTF and energy transitions in today's sustainability discourse and the broader climate change objectives. While end-user awareness and participation in policy and business model development are necessary for increased rural electrification, community-based energy planning may have additional positive effects. Several key questions pertaining to off-grid clean energy and electrical appliances uptake, ownership, use and value include; When to increase investments? When to strengthen markets? How to do this? What is more preferable to consumers and Why?

Literature evidence and the scenario analyses in the current study suggests that energy consumers purchase decisions are usually informed by utility metrics such as customers' WTP and the ATP of which to strike a purchase, the ATP should always be higher than the WTP [82]. However, beyond ATP and WTP metrics, there are some exogenous factors that will influence the customer's decision to buy an appliance. The adoption decision depends on the product, individual and the environment [83]. In India, [5], improving the quality of service was identified as crucial for increasing the electricity price (for example, hours of supply per day). Gendered ranking of appliances use needs better informs energy planning [18]. Li et al. [72], recommends a consideration of multiple factors, including local energy resources and economic, social, cultural and national geographical factors influencing, the rural household energy consumption structure [72]. Appliances may also have different values for instance: functional, social significance, epistemic, emotional and cultural [46, 47].

Three major themes have characterised energy governance and policy planning over the last decade: fragmentation, complexity and polycentricity, and to enhance effectiveness of off-grid appliance policies, government decision-makers and firms need to address these issues in the context of new technology, markets, and policy innovations at multiscale levels. The utility of a bottom-up ("polycentric) innovation approach to the off-grid appliance space and related development policy practices/planning are imperatives [16, 17]. Such innovative sustainable business models are availed for subsequent diffusion across different countries, contexts and domains. They demonstrate the value of polycentric climate governance in the investigation of the sustainable business model innovation [17]. Evidence from this Chapter shows that integrating appliance use, preferences and values in bottom-up consumer perspectives in appliance policy planning is one way to de-risk markets.

Supply decisions will thus be informed by Sustainable User preferences, user trends, and the user value attached to appliances. For example, adoption rates of SHS in Central East Africa, followed 3 phases (phase A, B and C) [84]. In phase A, distributors lacked a marketing strategy and most sales were garnered through the shops. In phase B, sales experienced an exponential growth as distributors adopted aggressive marketing strategies such as recruiting local sales agents and running local promotions for both urban and rural customers and in phase C, the distributor had halted down on promotional events and focuses more on customer services.

8.4.1 Derisking investments, climate change, investment and policy innovations

8.4.1.1 Investments

The major gap in existing financial incentives and strategies for elimination of market distortions strategies is centralised planning and a supplier-focus. East African countries adopted different strategies. Kenya strengthened its on-grid investment complemented by early support for off-grid. Whereas, Tanzania has low regulation on niche innovators enabling off-grid projects [85]. Fee-for-services, financial incentive and collaborative local efforts (local arrangements) are possible bottom up financial mechanisms. It would be important to explore their viability in promoting clean energy technologies and electrical appliances uptake, ownership and use in Rwanda. Options include payment strategies such as cost-sharing, hire purchase, renting or appliance financing which can be further explored from the user's perspective.

8.4.1.2 Climate change adaptation and mitigation

Previously, capacity building and support to negotiators and local institutions were recommended from the negotiators (including training and logistical support equipment [65, 86]. At the global policy level, gaps noted were: (i) intra-generational/equity where few Clean Development Mechanism (CDM), projects were implemented in Africa, (ii) design flaw in the United Nations Framework Convenction on Climate (UNFCC), because they failed to allocate emission rights to all countries (iii) a proper enabling environment where market based mechanisms could ensure funds flow from big-emitters to low emitters [86]. Finally, policy interventions to eliminate factors that constrain the operation of climate change mitigation related to private sector investment in poor countries. At the local level, appliance efficiency as a cheap pathway to low carbon emissions and its integration to local development initiatives is crucial. For example, decarbonisation strategies of the second meeting of the Conference of the Parties to the Minamata Convention on Mercury (COP2) are already 'ground-up'. Feed-in-tariffs were discussed earlier until technologies are mature and also user engagement (particularly key stakeholders using high carbon technologies).

8.4.1.3 Government policy and derisking country-risk

While the off-grid market has been left to private investors in most African countries, overall management of the energy policy including renewables is centrally managed by public utilities of which that is not a bad thing. Empirical evidence shows that there are governments that have preference for government control in the overall management of energy planning and great strides in electrification for instance Ethiopia and Tanzania. However, it is not clear how the appliance uptake strategy is managed alongside electrification rates. For some governments, private enterprises are extensively encouraged to participate in electrification, for instance Kenya, Nigeria and Ghana. Again the clean energy technologies and electrical appliances uptake strategy is not well articulated.

In Rwanda, the energy utility manages the energy plan, but the role of the private sector is explicitly stated and the launch of mini-grids and SHSs standards is a great step. However, an appliance uptake strategy is imperative and so are the specific initiatives and support mechanisms. Given the massive energy demand and appliance uptake projected in the off-grid markets there is need for GOR to further articulate consumptive, productive and service oriented support mechanisms of the energy and appliance uptake transition. Next steps on the policy framework could include measuring functional perfomance of technologies to adequately address arising issues on appliance loads [87].

8.4.1.4 Private enterprises nudges

Minigrids capacity to promote economic empowerment activities in households, small scale enterprises and other high consumption activities is a limitation in old designs. As private players transition from old designs to new designs, feed-in-tariffs may be suggested. Additionally, the 'arrival of the grid' is feared to disrupt off-grid businesses. In areas where the grid will eventually reach, there is need for clear indication on how they will be connected to the grid and that private investors will still recover their investments. Rwanda has clearly stated its full support to off-grid market players. Specific interventions highlighted in the Rural Electrification Strategy [41] include technical assessments and siting incentives by its private sector players also marked on an off-grid map. However, participation of local stakeholders in technical assessments and siting activities and the general

Pathways	Demand Stimulation Packages
Gendered pathways	Appliances for value-added agriculture Specification of the role of women in electrical appliance uptake strategies Considering the role of the HoH in appliance use Adoption of technologies and appliances for agriculture productivity Designing an appliance uptake strategy for the modern Rwandan household and role of women in energy efficiency Identification of women's time use and time saving appliances Skills and capacity building across Tier requirements
Financing pathways	Cost-sharing in appliance purchase Investments for appliance financing Micro-credit/Loans Private sector players finance schemes
Economic Activity and Energy Use Stimulation Pathways	Increasing production on existing agriculture land Energy efficient appliances Strengthening the consumptive-productive-service sector linkages Exploring appliance initiatives in the Made in Rwanda campaign and small scale enterprises (Agakiriro activities) Organise farmers-credit cooperatives/agriculture cooperatives Set up a division to promote electricity demand in cooperatives Sharing information about electricity uses Advocating for quality certified products Working with appliances companies to target the rural market Public equipment demonstrations Appliance campaigns

Source: Author.

Table 17.
The electric circus and its pathways in rural Rwanda.

development plans for local consumers' may be fully considered. Though a specific off-grid map shows potential sites, consideration of consumer needs and desires in new sites may strengthen business models.

8.4.1.5 The potential of the electric circus

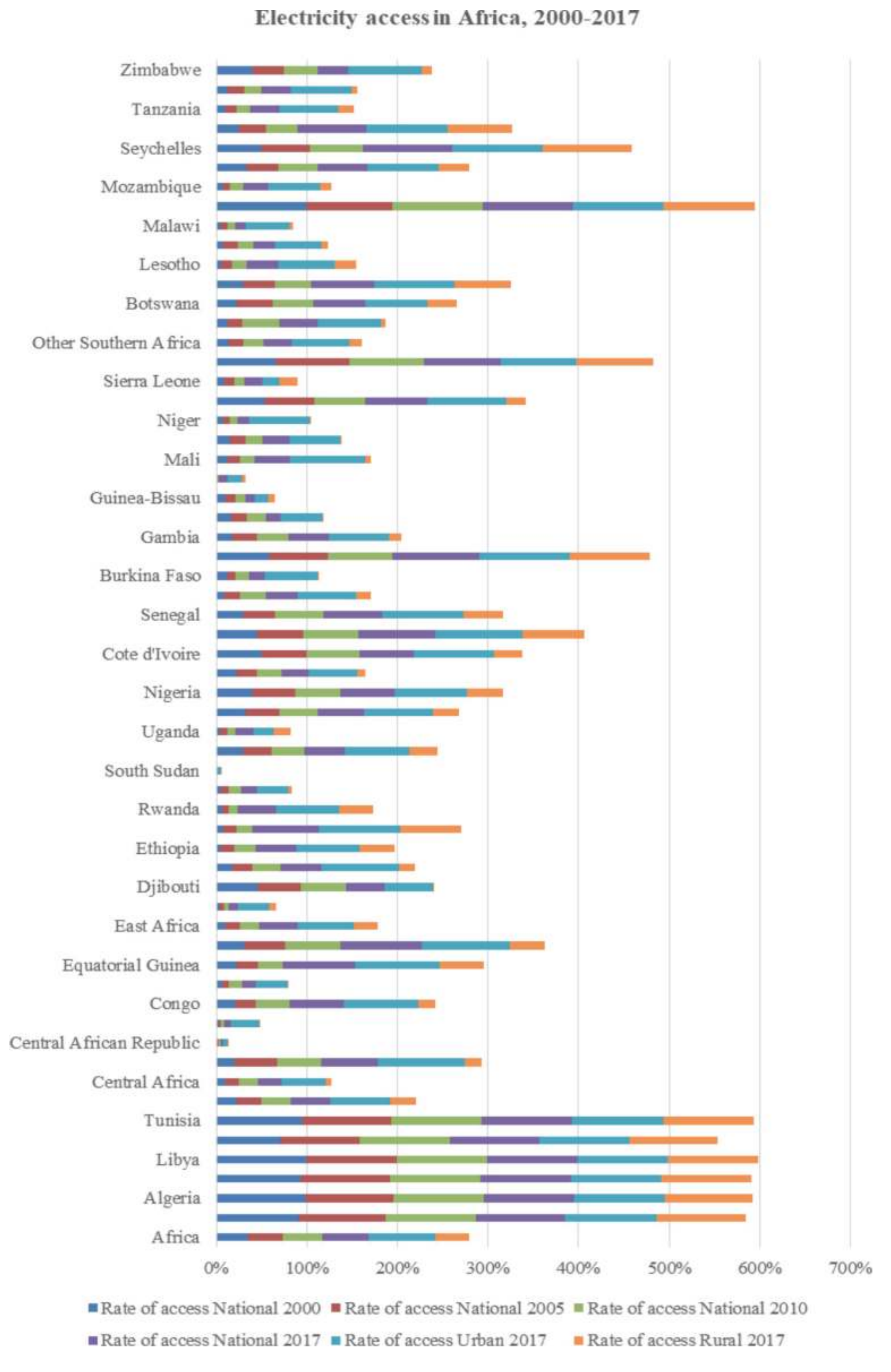
In summary the potential of electrification and electric appliances as was the case of the USA in the 1930s is a great case study for present day transitioning economies like Rwanda. The three pathways of a potential demand stimulation of energy and electrical appliances (**Table 17**).

Finally, the Chapter used a demand side characterisation approach to highlight systemic opportunities for stimulating appliance and energy demand at the intersection of the theory of change and the theory of agency. Three pathways emerging from the study focused on three themes: improving women and youth participation in productive use of energy and appliances, appliance financing and economic activity stimulation. However, as economies develop and experience economic growth a shift in the energy consumption approach is pertinent. The SEU model which has a transformative agenda underscores a consumer transition that leads to sustainable citizens. Its business model was used to influence derisking decisions which can influence investments, markets and policy innovations in a futuristic Rwanda. The pathways for a Rwandan Electric Circus were outlined.

Acknowledgements

I am grateful to the Editor and all the Editorial team and the assistance by many fine scholars too many to mention in this short work.

Appendix 1: Electricity Access in Africa, 2000–2017



Source: Ref. [49].

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