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DRIVERS FOR TRADITIONAL USE OF BIOMASS FOR DOMESTIC PURPOSES: A LITERATURE REVIEW AND A CRITICAL ANALYSIS

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Abbreviation Index

AAP	Ambient Air Pollution
ALRI	Acute Lower Respiratory Disease
BTSW	Botswana
CAM	Cameroon
Cap	Capita
COPD	Chronic Obstructive Pulmonary Disease
DCs	Developing Countries
ETH	Ethiopia
EWSA	Energy Water and Sanitation Authority
GHA	Ghana
HAP	Household Air Pollution
HH	Household
ICPS	Improved Charcoal Production Systems
ICSs	Improved Cooking Stoves
IHD	Ischaemic Hearth Disease
KEN	Kenya
LHV	Lower Heating Value
LPG	Liquefied Petroleum Gas
MEMD	Ministry of Energy and Mineral Development
MLI	Mali
MWI	Malawi
NGA	Nigeria
REPU	Renewable Energy Policy for Uganda
RWA	Rwanda
SEN	Senegal

SSA	Sub-Saharan Africa
TZA	Tanzania
UGA	Uganda
UN	United Nations
WHO	World Health Organization
ZIMB	Zimbabwe

Abstract

In Developing Countries, the energy needs of the household sector constitute a large share of the national energy requirements. Even today these needs are met by the use of traditional biomass with systems that are inefficient and harmful for health. This situation causes the onset of major diseases, the over-exploitation of forest resources and social problems which impede the development of these countries; for these reasons the current use of traditional biomass in Developing Countries is considered to be unsustainable. The aim of this thesis is to identify and discuss the main drivers influencing the consumption of biomass in a wide perspective to the whole scene of the Developing Countries, and to provide a basis for new studies and future actions. The approach that was adopted by the authors consists of a thorough analysis of the existing literature followed by a critical discussion and an original elaboration of the results. The conclusions highlight the importance of domestic dynamics in this field; particularly the socio-economic context, the availability of alternative energy sources, residence in a rural rather than in an urban area, the efficiency of the charcoal production processes, seasonal conditions, the ease of access to the wood, the family size and the habits related to the culinary tradition were found to be determining drivers for the traditional biomass consumption. Finally, given the importance that the issue will have in the near future, the authors hope that this work will be a useful starting point for future actions aimed at a more efficient and sustainable use of biomass.

Keywords: traditional biomass, household sector, developing countries, drivers for energy consumption, sustainability.

Sommario

Nei paesi in via di sviluppo, i bisogni energetici del settore domestico costituiscono una grossa percentuale del fabbisogno energetico nazionale. Tutt'oggi tali necessità vengono soddisfatte dall'uso di biomassa tradizionale mediante sistemi inefficienti e dannosi per la salute. Tale situazione è causa dell'insorgere di importanti malattie, del sovrasfruttamento delle risorse forestali e di problematiche sociali che bloccano lo sviluppo di questi paesi; per queste ragioni l'attuale uso di biomassa nei paesi in via di sviluppo è da considerarsi insostenibile. L'obiettivo di questa tesi è quello di identificare e discutere i principali fattori che influenzano il consumo di biomassa in una prospettiva estesa all'intero panorama dei paesi in via di sviluppo, in modo da fornire una base per nuovi studi e future azioni. L'approccio che è stato adottato dagli autori consiste in un'approfondita analisi della letteratura esistente seguita da una discussione critica e da un'elaborazione originale dei risultati ottenuti. Le conclusioni raggiunte evidenziano l'importanza delle dinamiche domestiche in questo ambito; in particolare il contesto socioeconomico, la disponibilità di fonti energetiche alternative, la residenza in una zona rurale piuttosto che in una urbana, l'efficienza dei processi di produzione del carbone di legna, le condizioni stagionali, la facilità di accesso alla biomassa, la dimensione del nucleo familiare e le abitudini legate alla tradizione culinaria sono risultati essere fattori determinanti per il consumo di biomassa tradizionale. Infine, considerata l'importanza che il tema manterrà nel prossimo futuro, gli autori si auspicano che questo lavoro possa costituire un utile spunto per future azioni mirate ad un uso più efficiente e sostenibile della biomassa.

Parole chiave: biomassa tradizionale, settore domestico, paesi in via di sviluppo, driver per il consumo energetico, sostenibilità.

Introduction and objective

This thesis work aims at addressing a specific issue of the challenge for access to modern, high quality and reliable energy, namely the reliance on traditional biomass fuel used in inefficient and unsafe systems. Though often not it in the spotlight, this issue involves around 3 billion people worldwide – almost all of them living in Developing Countries (DCs) – and constitutes a threat to the environment, to people health and to economic and social development of the involved countries. Causing serious diseases to population, overexploiting the forest resources and clipping the wings of development, the current use of biomass in DCs is to be considered unsustainable. Most important, the International Energy Agency prospects for 2040 show no significant improvement of the situation [1]. Since the desired results are still far from being achieved, there is a strong need of researches about factors and dynamics which influence energy choices and consumption behaviours of households, to constitute a guideline for future actions aimed at a sustainable use of biomass. Furthermore, there is a severe shortage of studies leading international analyses regarding the relationships between socio-economic factors and the household consumption rates of traditional biomass. The present work is therefore aimed at a literature study of these relationships followed by a critical analysis of results obtained, providing a baseline for further studies in a perspective that seeks to embrace the whole panorama of Developing Countries. About one hundred and sixty among scientific papers, publications, conference proceedings and grey literature reports were considered by the authors to obtain quantitative information about household consumption and drivers that influence them. Successively, a study of this results brought to development of a critical discussion for each identified relationship in a general and non-local perspective.

Chapter 1 is dedicated to an overview of access to energy in Developing Countries. Impact on health, environment and on the society is analysed in depth and the issue of unsustainability of the current use of biomass is introduced.

Chapter 2 focuses on literature analysis of one hundred and fourty studies about drivers influencing household consumptions of biomass and, successively, on a critical elaboration of results obtained from these researches. In particular, it is proposed for each driver a critical discussion that embraces the phenomenon at an international level, analysing the causes and explaining the reasons that bring to these conclusions.

Finally, in the *Conclusions*, an overview of all analysed factors is provided, giving a synthesis of the main findings. On the base of what emerges from the thesis work, the chapter includes also authors critical opinions about the considered issue and possible starting points for further studies.

1 Access to energy in Developing Countries

Access to modern, high quality and reliable energy is a fundamental prerequisite to underpin human development and improve quality of life. Many Developing Countries are grappling with the challenge of energy poverty to achieve economic and social development. The necessary goals to conquer this challenge are:

- access to modern energy for productive activities and for public services
- household access to a minimum level of electricity and to safer and more sustainable cooking and heating fuels and stoves [1].

In this study focus is placed on household lack of access and on impact of this issue on health, environment and society. In this sense, many efforts have been made to improve the conditions but results have been poor, especially in sub-Saharan Africa where more than 620 million people remain without electricity and nearly 730 million continue to rely on traditional biomass for cooking [1].

In Africa, efforts to bring access to electricity are outpaced by rapid population growth which becomes more critical in rural areas where households are hardly reached by the grid. The situation is even more complex as regards access to clean cooking facilities where a transition to modern fuel is not straightforward. Because of a phenomenon known as "fuel stacking" people may continue to use solid biomass for cultural or affordability reasons, even if they have access to modern and cleaner fuels. In rural areas solid biomass is the most used fuel almost everywhere while in urban centres the choice of fuel is much more varied. These considerations are clearly visible in Figure 1.1.

Accounting for 70% of final energy use in sub-Saharan Africa and being used principally for household cooking needs, solid biomass has today adverse environmental consequences linked to overexploitation of natural resources and health effects linked to indoor air pollution. It is expected that these problems persist in the near future, since it is estimated that 650 million people still cook with biomass in an inefficient and hazardous way in 2040 [1].

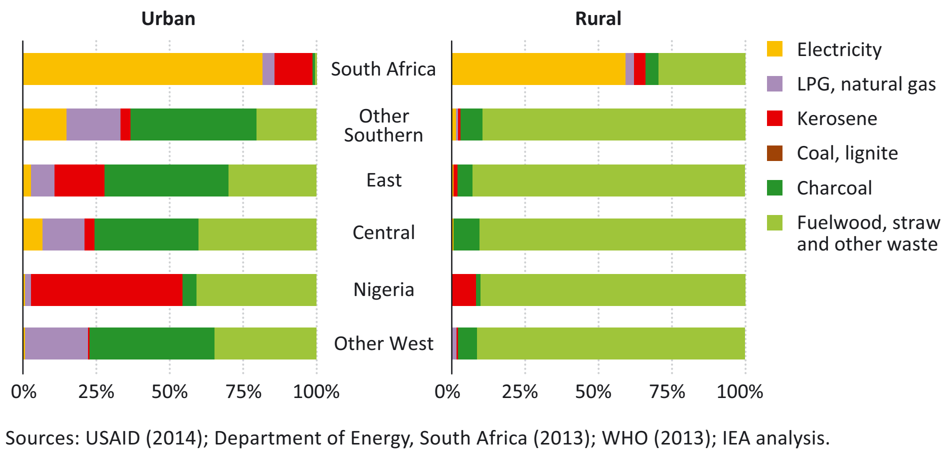

Figure 1.1 - Main fuel used by households for cooking in SSA [1].

However, this issue does not affect only Africa but it is a global challenge. Currently, about 1.5 billion people in developing countries lack access to electricity and nearly 3 billion people use solid fuels (traditional biomass and coal) in open fires and traditional stoves for cooking [2]. Most of these people live in low- and middle-income countries in developing Asia, Africa, Latin America and the Middle East as shown in Table 1.1.

Improved cooking stoves (ICSs)[1] are used only by a small share (fewer than 30 percent) of population reliant on solid fuels for cooking. Almost 830 million people in Developing Countries use ICSs for their cooking needs but more than two-third of them live in China, while sub-Saharan Africa accounts for only 4 percent of people using this cooking systems [2]. So, a large majority of people in these countries continue to cook in an unsafe and unsustainable way, relying on use of

[1] An "Improved Cook Stove" is a stove characterized by an improvement, compared to a traditional stove, in all the performance indicators linked with the issues due to biomass traditional use: Thermal Efficiency, Specific Consumption of fuel, Time to boil, CO emissions and PM emissions [69].

solid fuels burned with inefficient cooking systems, such as the traditional three-stone fire.

Region	**Population relying on traditional use of biomass** [millions]	**Percentage of population relying on traditional use of biomass**
Developing countries	2.722	50%
Africa	754	68%
North Africa	1	0%
Sub-Saharan Africa	753	80%
Developing Asia	1.895	51%
China	450	33%
India	841	67%
Latin America	65	14%
Brazil	8	4%
Middle East	8	4%
WORLD	2.722	38%

Table 1.1 – Population relying on traditional use of biomass for cooking in 2013 [3].

This global issue constitutes a threat to the environment, to people health and to economic and social development of the involved countries. Following sections are dedicated to a specific analysis of impacts on these aspects.

1.1 Impact on health

Lack of access to clean, efficient, modern energy in the home can impact health in many ways. Burning solid fuels, often indoor on open fires and simple stoves, releases large amounts of smoke from incomplete combustion that is responsible of domestic air pollution. Consequently, the health of all members of the family is threatened, especially that of women and children who are further subject to this type of pollution [2].

At global level, almost 4.3 million deaths are attributable to household air pollution (HAP) in 2012 and 99% of them occurs in Developing Countries. In particular, there are evidences on a link between some toxic substances present in the smoke produced by use of solid fuels and the contraction of important disease, such as: acute lower respiratory disease (ALRI), chronic obstructive pulmonary disease (COPD), lung cancer, cerebrovascular diseases (stroke) and ischaemic heart diseases (IHD). Deaths for household air pollution, distributed by disease are shown in Figure 1.1.1 [4].

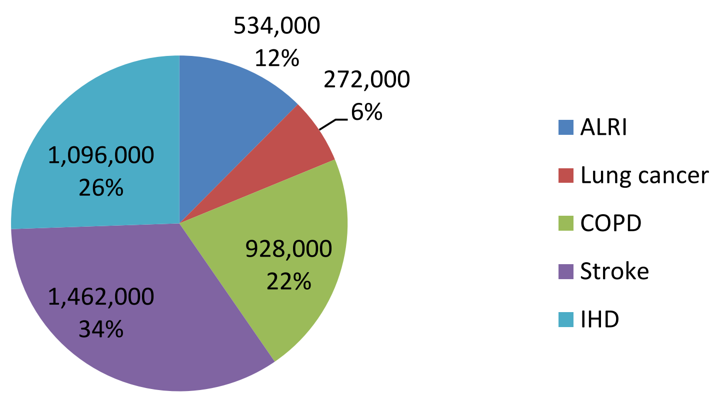

Figure 1.1.1 – Deaths attributable to HAP in 2012, by disease [4].

Although women are exposed to smoke for longer period because of their greater involvement in cooking activities, the absolute burden is larger in men due to larger underlying disease rates in men [4]. However, considering the principal respiratory diseases, 60% of all deaths from COPD and lung cancers are registered among women [2].

Considering WHO guidelines, the concentrations of particulate matter are up to 20 times higher than recommended. This damages human health in different ways such as: direct injury and irritation through deposition in the lungs, impairment of defences by disruption of immune cell functions, oxidative stress in the lungs and throughout the body due to absorption of the very smallest particles in the blood stream. For carbon monoxide, the recorded concentrations indicate exposures that are equivalent to light- to medium levels of active smoking or heavy levels of passive tobacco smoking. This exposition can be even more critical for pregnant women, who traditionally continue to fulfil their cooking duties throughout pregnancy [2].

Pollutants substances influence also the quality of ambient air, that is responsible of the same diseases reported for indoor spaces. Globally, 3.7 million deaths were attributable to ambient air pollution (AAP) in 2012 and about 88% of them occur in low- and middle-income countries. Considering results from both phenomena and assuming an approximation of the combined effects, it emerges that 7 million deaths were attributable to the joint effects of household (HAP) and ambient air pollution (AAP) in 2012, at global level [4].

1.2 Impact on environment

The use of wood for cooking in low efficient devices by millions of people constitutes a threat for forest natural resources and deforestation is a consequence of this behaviour that is dangerous for local environment [5].

Quantitative and qualitative studies demonstrate that forest perform many protective functions, such as:

- Protection of soil and water resources. Forests conserve water by increasing infiltration and decreasing sedimentation, by reducing runoff velocity and surface erosion. They regulate water yield and flow, they mitigate salinity and filter present pollutants, they control floods and enhance precipitations. So forest can contribute to protection of arid areas, coasts, rivers and watershed.
- Control of desertification. Overexploitation of wood resources cause phenomena of land degradation and creates problems for natural water resources, favouring desertification of territories.
- Mitigation of climate and filter of air pollution.
- Conservation of ecosystems with local flora and fauna protection.

Globally, annual wood removals in 2005 amount to 3.4 billion cubic meters and fuelwood account for about half of this quantity. This data constitutes an underestimate of real amount of wood removed because it must be accounted a quantity of wood that is informally and/or illegally collected. Figure 1.2.1 shows rates of this phenomenon in world continents, distinguishing industrial round wood and fuelwood for different years.

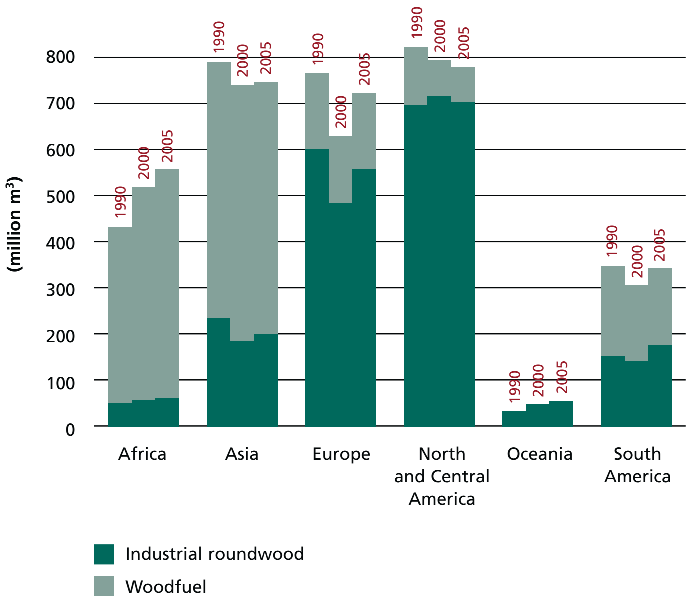

Figure 1.2.1 – World trends in wood removals for industrial round wood and fuelwood [5].

Numerical values of wood removals by region and sub-region are reported in Table 1.2.1. Reading this, it is clear that in North America, East Asia, Europe and Oceania removals are mainly linked to industrial sector while fuelwood purpose dominates in Africa, Central and South America, and Southeast Asia.

Region	**Industrial wood** [million m³]	**Fuelwood** [million m³]	[%]	**Total removals** [million m³]
Eastern/Southern Africa	39	292	88	331
Northern Africa	4	24	87	27
Western/Central Africa	30	301	91	330
Africa	72	616	90	688
East Asia	86	71	45	157
South/Southeast Asia	99	464	82	562
Western/Central Asia	17	13	43	30

Asia	201	548	73	749
Europe	568	167	23	735
Caribbean	1	5	82	6
Central America	4	17	81	22
North America	701	55	7	756
North/Central America	706	77	10	783
Oceania	55	1	1	56
South America	180	167	48	347
World	1783	1576	47	3359

Table 1.2.1 – Wood removals in world regions for industrial wood and fuelwood (2005) [5].

From these data it is possible to understand how important is fuelwood for the wood natural resources management in Africa, where it accounted for 90% of total wood removals in 2005. In the next decades, wood removals are expected to increase globally because of population and income growths, which conduce to higher demand of wood products [5].

Another environmental impact of unsustainable use of wood for households needs regards greenhouse effect and the global warming issue. Some substances contained in smoke from incomplete combustion have global warming effects. Even when biomass is renewably harvested, avoiding increase of atmospheric CO_2, the carbon-based fuels burned in traditional stoves release other greenhouse substances such as: black carbon, volatile organic compounds, carbon monoxide and methane. It must be considered that the climate warming effect of household energy use in DCs is not great but it is however significant [2].

1.3 Impact on society

Wood collection is an activity that requires considerable amount of time which is linked to opportunity costs that constrain socio-economic development of countries where it is an important subsistence task; this phenomenon is known as "time burden". Furthermore, this burden, falling principally on women and children, subjects the firsts to risk of injury and violence and causes missing time for education of the seconds [2].

A good estimate of the amount of time stolen to people emerges from an energy survey that is part of the Millennium Villages Project [6] and it is shown in Table 1.3.1.

Sites	**Number of weekly trips per gatherer**	**Hours spent collecting fuelwood per gatherer per week**	**Typical roundtrip distance (km) per collection per trip**
Bonsaaso (GHA)	3.2	6.7	4.3
Dertu (KEN)	3.4	6.7	6.6
Ikaram (NGA)	1.6	4.0	5.5
Mayange (RWA)	2.8	7.1	4.1
Mbola (TZA)	1.9	N/A	N/A
Mwandama (MWI)	1.8	2.9	2.2
Pampaida (NGA)	3.0	4.0	2.1
Potou (SEN)	5.2	10.8	4.0
Ruhiira (UGA)	2.6	4.5	1.9
Tiby (MLI)	2.3	7.7	10.3
Average (all sites)	**2.8**	**6.0**	**4.6**

Table 1.3.1 – Time spent and distances travelled during fuelwood gathering activity [6].

Representing a set of African sites, this study provides a good picture of the issue in Developing Countries. Average time spent collecting wood is 6 hours per gatherer each week, ranging from a minimum of 2.9 hours per week to a maximum of 10.8 hours per week. Fuelwood gathering is undertaken by women and to a less degree by girls while adult men represented only a small fraction of gatherers. Transport of gathered wood is made in almost all cases by foot without the aid of any equipment or animals, consequently it is a strenuous activity that requires a lot of energy. Looking to time spent and distance travelled, it is clear that this kind of activity steals to people time that could be used for productive activities and for improve education levels of child so that the socio-economic impact becomes more significant than it might be expected.

An environmental issue which has also influence of society is the sand encroachment, an effect of desertification derived by overexploitation of wood resources which has important socio-economic impacts such as: reduction of arable and grazing land, decrease of water resources availability, reduction of agriculture productivity and as a consequence of previous point threat for food security and livelihoods of local communities [5].

2 Drivers for Traditional Biomass Consumption

In this chapter, we have conducted a deep analysis of the studies and data available in literature and successively we have produced a critical discussion of them to arrive at a single and inclusive result for each driver. About one hundred and sixty among scientific papers, publications, conference proceedings and grey literature reports were considered to extrapolate data on the main factors that influence the biomass use in Developing Countries and to explain the underlying dynamics of these relationships. The authors aimed at producing a discussion that generalize the results of the various studies considered, trying to go from a local to a broader and international perspective.

2.1 Season

The present section investigates the possible relationship between season changing and traditional biomass consumption in DCs. The literature analysis – twenty papers were considered for this driver, mainly based case-studies from SSA – showed that, for the influence on biomass use, it is suitable to distinguish two or three different seasons (*e.g.* dry, rainy), depending on the specific geographic location of the analysed country, rather than considering the usual four season (spring, summer, fall, winter) division. Moreover, the analysis allowed us to identify five key factors (or *sub-drivers*) that are linked to seasonal changing and that directly affect biomass consumption, namely:

1. Heating energy needs;
2. Seasonal activities;
3. Variations of household size along the year;
4. Availability and prices;
5. Moisture content.

2.1.1 Literature analysis

Two seasons – dry and rainy – were identified in Botswana [7], Cameroon [8], Ethiopia [9], Ghana [10], Lesotho [11], Mozambique [12], [13]. A three seasons pattern: hot and dry, hot and rainy, and cool and dry, was recognised in Malawi [10], [14], Mali [15], and Mozambique, South Africa, Zambia [16]. Finally, a classic four season scheme was preferred in Rwanda [17] and South Africa [18].

In this sub-section, each of the five previously defined *sub-drivers* is analysed based on data from the available regions.

2.1.1.1 Heating energy needs

As easily foreseeable, during cold and rainy seasons biomass consumption increases to meet the space heating energy need. In a village in southern Mali, data states that fuel wood consumption raises from 0.79 kg/capita/day during hot season to 2.41 kg/capita/day in the cold season [15]; this means a three times higher biomass use, which represents a big share of total energy needs of a household, even though for a relatively short period. Other studies show that in Botswana and Malawi cold season is a driver for increasing biomass consumption as well [7], [19]. In the report of Geissler et al. [9] some data are available to compare dry and wet seasons' fuel wood consumption in Ethiopia on a quantitative point of view, and as shown in Figure 2.1.1, it is possible to notice that during wet season consumption rates are always greater than in dry ones.

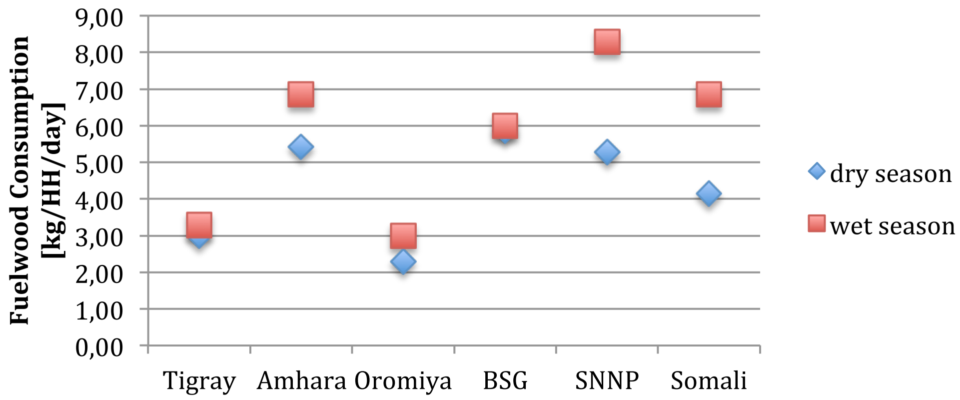

Figure 2.1.1 - Fuelwood consumption in different Ethiopian regions [9].

2.1.1.2 Seasonal activities

To each period correspond different seasonal activities, that can influence biomass consumption in a twofold manner, needing more or less energy to be carried out, and leaving a different amount of remaining time to dedicate to biomass collection. In SSA, a world dominated by subsistence agriculture, biomass collectors are farmers as well, and this means that their activities follow the rural calendar in the seasons succeeding. As a result, wood exploitation is less intense during the rainy season, when cultivation requires the biggest effort [20], and more acute in the dry once, where farming activity is not occurring [8]. Brouwer and Falcão [21] show how, during the rainy season in Mozambique, the combination of the decreased ease of access to resources and the reduced time free from harvesting crops and available to collect fuel wood, results in a price growth. Figure 2.1.2 [22] represents data from Mali and again gives an immediate idea of how wood collection is related to farming activity and precipitations. It is possible to recognize that wood harvesting is done mainly during the dry season, when agricultural tasks are minimal and the collection is easier. The month of march represent an exception since is dedicated to rest. A similar seasonal behaviour in wood collection is reported also in Zimbabwe, with the relative seasonal shift [22].

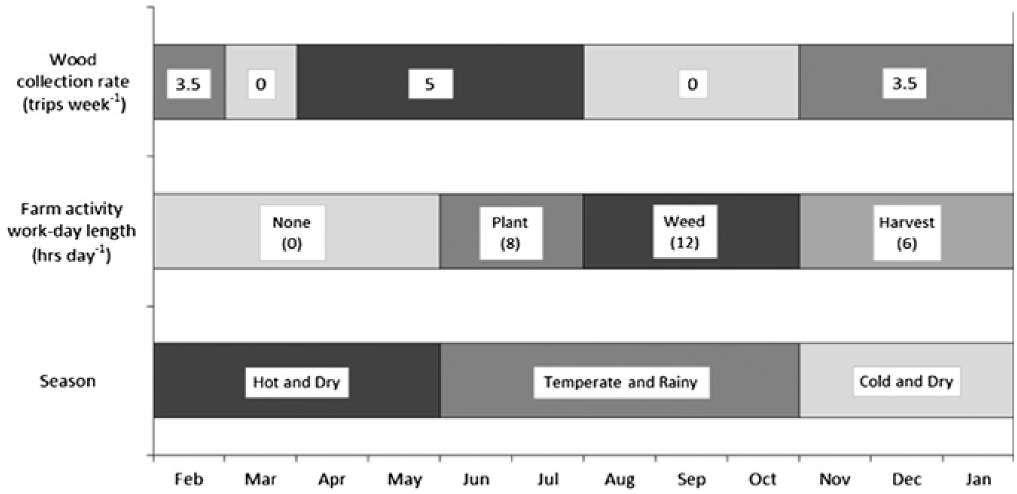

Figure 2.1.2 - Yearly cycle for wood collection, farming, and seasons [22].

Another interesting analysis [22] shows the yearly scheme of wood consumption for domestic activities, Figure 2.1.3.

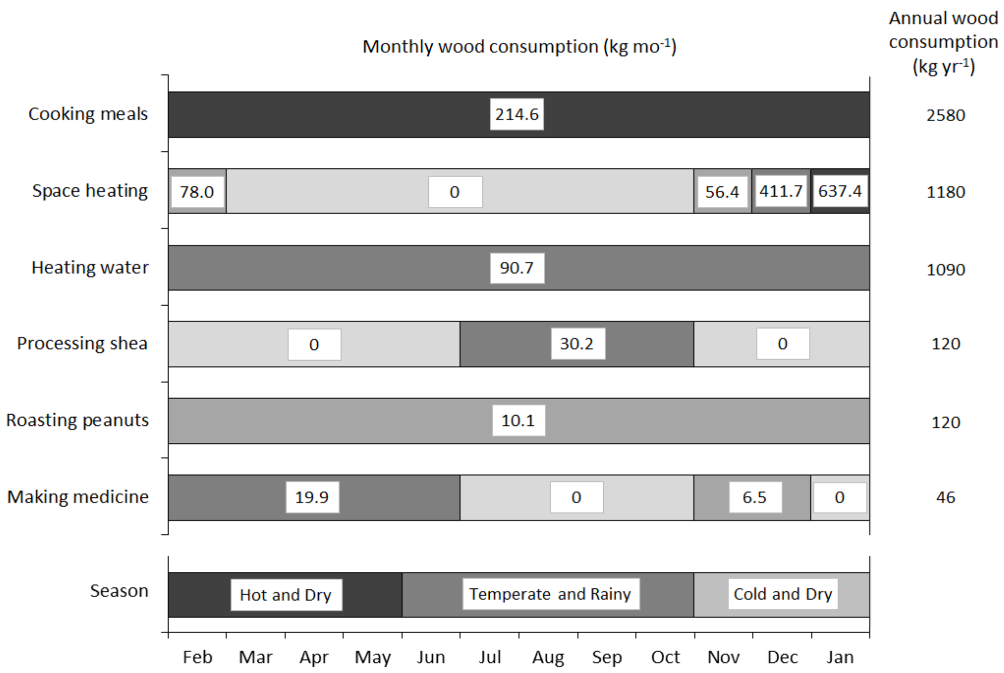

Figure 2.1.3 – Wood consumption by activity for a family of 13 people [22]

It is noticeable how many activities cause seasonal variations in the biomass consumption, but most have just a marginal relative impact. Hence, it results that in Mali the main energy consuming actions are cooking meals, water heating – which were found to be steady along the year [23] – and space heating, which thus results as the big contributor to seasonal consumption pattern changes. This conclusion is consolidated by Ochieng [24], showing that in rural Kenya, where fuelwood is not adopted for heating but for cooking only, seasonality does not play an important role in driving fuel consumption. In Botswana, hot water is heated less in summer by 63% of households [7]. It is also stated that changes in biomass use related to seasonal change are in the order of 260% in the domestic sector, for 350% for artisans and for 210% in transports [22].

2.1.1.3 Variation of household size along the year

The total amount of biomass consumed by households strongly depends on the number of people leaving in a house. Here, we want to underline how the seasonal pattern influences the household size, which in turns influences the biomass consumption as shown in 2.2. In SSA, many people live of subsistence agriculture; this means that seasonal migration is a typical phenomenon. For instance, it was found [15], [23] that villagers in Mali moved from the villages to small farms, and Mahiri [25] individuated boarding school as another factor leading to family sizes variation, causing a decrease in the energy consumption that can be measured in the village. It is thus important, in order to have a correct understanding and measurement of the traditional biomass consumption, and to make any assessment, to consider such seasonal variations because they can lead to inaccurate considerations.

2.1.1.4 Availability and prices

Seasonal patterns influence the availability and price of the different biomass sources: here is a brief description found in literature of how this happens. The consequences on effective biomass consumption of these changes are better described in the relative section 2.6. Being in the dry or in the wet season, it causes differences in the availability of traditional biomass. In the wet season, in fact, two factors affect biomass consumption: the increased difficulty to harvest, that causes a labour time and cost increase, and the worsening road problems, resulting in a transport cost increase [20], [21]. In another study [8], a Cameroon's merchant behaviour is descripted, where in the wet season they sell smaller bundles for the same price of the dry one. This is explained as a reaction to the decreased amount of wood entering the urban market. The relative availability of the different biomass fuels changes along the year, causing shifts between the different fuel types, such as fuel wood, crop residues and dung [18]. Round wood and charcoal are more used in the rainy season, branches, leaves, twigs and crop residues in the dry: this happens because the formers are less subjected to got too wet [9], [10]. Reasonably prices of each different biomass source changes along the year, in function of the season.

2.1.1.5 Variation in biomass energy content

Typically during the rainy season, biomass is more wet, and the increment in moisture content cause a reduction in the fuel heating value: this means that it is necessary to increase the amount of fuel burnt, in order to satisfy the energy need. To illustrate this phenomenon and to give it a numeric quantification it is reported Table 2.1.1 [23], where the authors acquired wood samples in Mali in order to assess the moisture content:

Month of data acquisition	**Season**	**Moisture content mean** (range) [percentage in weight]
May	Hot and dry	10.9 (10.2-12.2)
August	Temperate and rainy	18.3 (13.6-43.1)
December	Cool and dry	7.7 (6.2-12.9)

Table 2.1.1 – Seasonal variation in wood moisture content on an as-received basis [23].

As it is possible to notice from Table 2.1.1, the amount of moisture in fuel wood has wide variations along the year, being about double in the rainy period; this means a clear reduction in the biomass energy content per mass unit, with a consequent need for an increase of fuel wood consumption, in order to fulfil the energy need.

Moreover, as underlined by Adkins et al. in [6], it is necessary to take into account the affection of water content in wood, in order to correctly compare fuel wood consumption in different seasons; otherwise the risk of overestimate energy consumption during rainy periods occurs.

2.1.2 Critical analysis

In this chapter, we had investigated in the literature how traditional biomass consumption in SSA is influenced by seasonality. First it was found that it is appropriate to base every consideration on a "natural" season scheme, which means not to consider months or four seasons but to divide the year into homogeneous climate-precipitation periods. Then we found out that there were not any specific studies in the literature analysing the link between seasonality and consumption, but it was possible to find data from different regions and to build a transversal analysis. Thus we detected five important topics to considerate in order to investigate this driver, since these factors vary along seasons and influence biomass consumption. They were: heating needs, seasonal activities, variations of household size, availability of sources and moisture content. It emerged that, during cold-rainy seasons, biomass consumption increases due to the combined influence of several factors, that add their effects together. In fact, the energy need for space heating increases - this is the main activity influencing consumption in the domestic sector - and agriculture is not going on taking people out of villages, which results in higher family sizes: a significant driving factor increasing total household biomass consumption. Moreover, to worsen the consumption status, in this period the amount of moisture in wood is higher, which results in a lower LHV. Finally, not only consumption but even collection is more concentrated in in this period, because pause in agricultural tasks leave time for biomass collection.

Unfortunately, we observed a real lack of accurate numerical, widespread observations.

Here we report Figure 2.1.4 [15], one of the few study that tried to investigate seasonal variations related on energy consumption with a deep and quantitative approach, in order to underline how relevant the impact resulting from this driver could be.

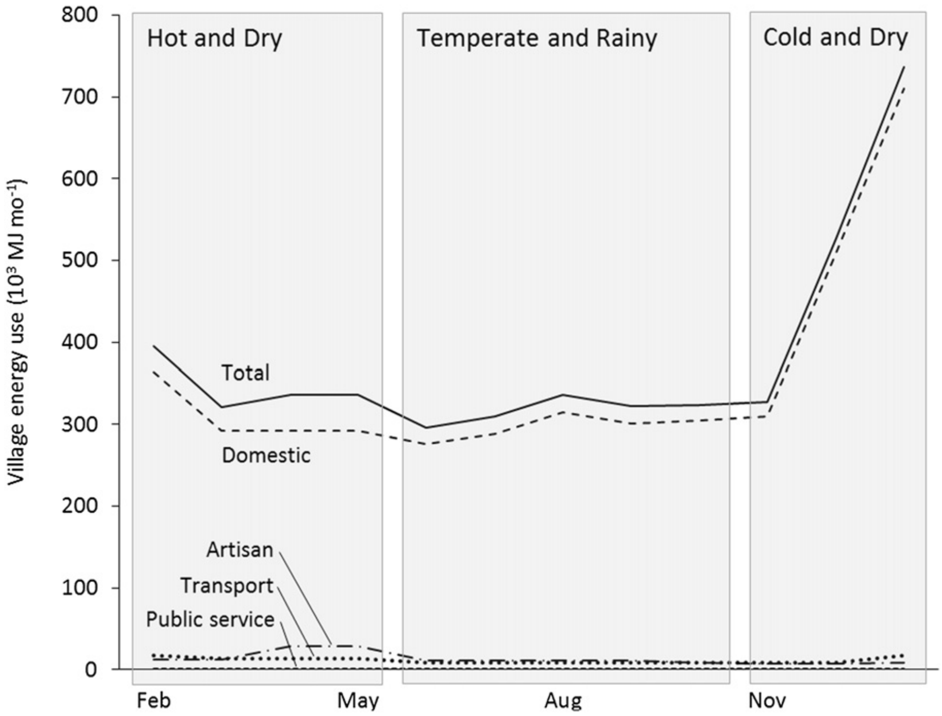

Figure 2.1.4 - Variations in energy use across one year [15].

2.2 Family size

In Developing Countries (DCs), there is a strong relationship between household dynamics and fuelwood consumption, as demonstrated by several studies conducted in recent years [26]. Considering a worldwide dimension, empirical results show that nations with higher average households size consume less fuelwood per capita. In a similar way, several national studies and models revealed an inverse relationship between the number of household members and fuelwood consumption. These findings suggest the presence of economies of scale regarding family consume of fuel [26].

In countries that the study generically defines as 'less developed' [26], the average household size decreased from 5.1 to 4.4 from 1970 to 2000 (Keilman 2003) and in the same period this trend was accompanied by a steady increase in the number of household, as a result of population growth. It is clear that these two trends lead to an increase in wood consumption, considering proportionality between demand of fuel and total population in connection to reduction of economies of scale linked to household size.

2.2.1 Literature analysis

Several researches have dealt with wood consumption in sample areas, leading to a study of relationship between it and household size. In particular, we analysed data from seven scientific papers.

Results of those studies, referred to different geographical areas, are shown in Table 2.2.1, grouping African countries, and Tabel 2.2.2 grouping Asian countries. Details regarding the methods of data collection for the specific cases are discussed below.

*Wood Consumption [kg/ day*capita]*

Family Size	**Malawi**	**Mali**	**Nigeria**	**Zimbabwe**
3	2.28	/	1.67	5.32
5	1.54	2.04	1.20	3.83
7	1.22	/	1.11	3.36
9	1.04	/	0.99	3.22
10	0.98	1.26	0.95	3.19
12	0.89	/	0.94	3.16
13	0.85	1.08	0.91	3.16

Table 2.2.1 – Wood consumption for different family sizes in Africa [15], [27]–[29].

*Wood Consumption [kg/ day*capita]*

Family Size	**Bangladesh**	**Cambodia**	**India**
3	2.68	2.84	4.34
5	2.02	2.16	3.48
7	1.69	1.87	2.7
9	1.55	1.39	/
10	/	/	2.55
12	1.18	/	/
13	/	1.49	2.15

Table 2.2.2 – Wood consumption for different family sizes in Asia [30]–[32].

For the case of Malawi, it is considered a study conducted in rural villages of Chembe and Msaka [27]. It is considered the amount of firewood used for domestic needs, principally cooking and water heating, while space heating has been overlooked because local climate is hot and equable. The collected data show a clear economy of scale in household wood consumption. It is observed that a two-person household have a consume of over 20 kg/cap*week while larger families are characterized by more modest values. To investigate the relationship between per capita wood consumption and family size, an inverse curvilinear model was used by the authors [27], generating the equation:

$$y = 2.98 + \frac{39}{x}$$

where y is the weekly per capita wood consumption and x is the number of members present in the household.

For the case of Mali, it is considered a study conducted in a rural village [15]. In terms of mass, the village average consumption of wood results to be 1.03 kg/cap*day counting 0.54 kg/day*cap for cooking, 0.23 kg/day*cap for water heating, 0.19 kg/day*cap for space heating, 0.026 kg/day*cap for roasting peanuts, 0.006 kg/day*cap for making tea, 0.028 kg/day*cap for shea processing and 0.01kg/day*cap for medicine. Domestic wood consumption for a family of 13 members (near to the average family size of 12.8) is 1.08 kg/day*cap which is equivalent to 15.98 MJ/day*cap, assuming a lower heating value (LHV) of 14.8 MJ/kg. Using the same assumptions, wood consumption for families of 5, 10, 20 or 40 people is respectively 2.04, 1.26, 0.87 and 0.68 kg /cap*day. There is a clear evidence that family size is inversely linked with daily energy needed for cooking, confirming presence of economies of scale in wood consumption. As family size increased from 5 to 20 members, the required energy decreases from 30.2 MJ/cap* day to 12.9 MJ/cap*day.

For the case of Nigeria, results refer to a study conducted in rural and urban areas of Ile-Ife [28]. It is considered the consumption of wood for cooking of different families living in rural areas. Collected data show that with increasing family size, per capita consumption falls. The most important savings are initially obtained, after which the rate of consumption stabilizes for larger families. In this case, data were graphically reported in a figure, and have been extrapolated by means of a specific software.

For the case of Zimbabwe, data are extrapolated by an annual study of 2006 [29]. Biomass consumption for all domestic needs was studied, revealing that per capita consumptions rates for fuelwood are inversely related to household size. In order to describe this relationship the authors proposed the following equation:

$$y = 3.15 + 12.36e^{-0.58x}$$

where y is the daily per capita wood consumption and x is the number of people constituting the family. We can see from Table 2.2.1 that consumption rate decreases exponentially up to a family size of about eight persons while beyond this point it remains more or less constant.

For the case of Bangladesh, it is considered a study conducted in the rural floodplain areas [30]. It is considered the wood consumed annually for household cooking by a sample of families living in rural areas. The study shows that family size significantly affect the amount of wood used per family. As expected, large families consume more fuelwood; accordingly, consumption is positively correlated to family size. Nevertheless, the very large families present a low value of per capita consumption while the smaller families are characterized by higher per capita use. Estimated wood fuel consumed result to be 2.94 tonne/family*year for very small families of 3 persons, 3.69 tonne/family*year for small families of 5 persons, 4.31 tonne/family*year for medium families of 7 persons, 5.09 tonne/family*year for large families of 9 persons and 5.16 tonne/family*year for very large families of 12 persons.

For the case of Cambodia, it is considered a study conducted in Chumriey Mountain, in Kampong Chhnang Province [31]. Data were collected in order to explore wood consumption rate for cooking and boiling water activities. Also in this case, results show that smaller families are less efficient in fuel uses while larger families are characterized by lower per capita consumes of wood. Annual wood consumption for cooking is 663.62 kg/capita*year for very small families of 3 persons, 521.27 kg/capita*year for small families of 5 persons, 429.86 kg/capita*year for medium families of 7 persons, 334.71 kg/capita*year for large families of 9 persons and 354.26 kg/capita*year for very large families of 13 persons. In the same way, annual wood consumption for boiling water is 373.83 kg/capita*year for very small families of 3 persons, 267.00 kg/capita*year for small families of 5 persons, 252.69 kg/capita*year for medium families of 7 persons, 174.17 kg/capita*year for large families of 9 persons and 188.83 kg/capita*year for very large families of 13 persons. The table above shows the sum of the two contributors, referred to the daily consumption.

For the case of India, it is considered a study in Uttara Kannada District, in Karnataka State [32]. Levels of consumption are estimated considering cooking and water heating, while space heating is not computed because it is present only in some periods of the year and in some areas at different level. The study proposes a method to refine the assessment of family size, assuming the conversion factors listed below in Table 2.2.3 with which it is possible to compute number of adult equivalent of the number of people per household. Consequently, household size is referred to amount of adults present in the family.

Family Component	**Standard Adult Equivalent**
Men 18-59 years	1
Women 18-59 years	0.8
Men > 59 years	0.8
Women > 59 years	0.8
Boys 5-18 years	0.5
Girls 5-18 years	0.5
Kids 1-5 years	0.35
Child > 1 year	0.25

Table 2.2.3 – Conversion factors to compute number of adult equivalent [32].

Data show that increasing adult equivalents per household reduce average per capita fuel consumption. Using number of adults equivalent, daily wood consumption for cooking is 2.35 kg/capita*day for 3 adults, 2.15 kg/capita*day for 5 adults, 1.67 kg/capita*day for 7 adults, 1.62 kg/capita*year for 10 adults, and 1.42 kg/capita*day for 13 adults. In the same way, daily wood consumption for boiling water is 1.99 kg/capita*day for 3 adults, 1.33 kg/capita*day for 5 adults, 1.03 kg/capita*day for 7 adults, 0.93 kg/capita*day for 10 adults and 0.73 kg/capita*day for 13 adults. Summing the two contributors, data in the Table 2.2.2 were obtained.

2.2.2 Critical analysis

A graphical correlation Figure 2.2.1 between wood consumption and family size has been derived and elaborated based on data from all countries previously discussed.

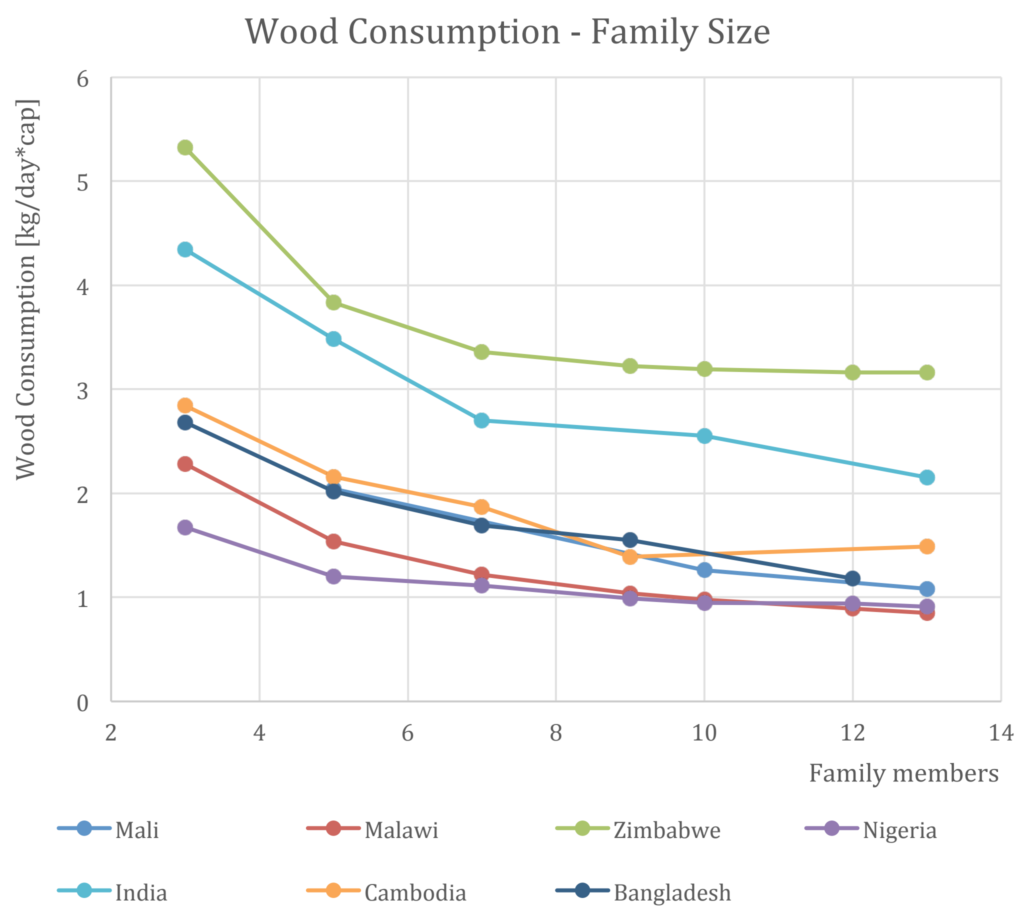

Figure 2.2.1 – Wood consumption for different family sizes in African and Asian countries [15], [27]–[32].

Changes in rate of consumption between different countries are due to local conditions of areas considered by the related study. In particular, biomass availability and the account of space heating have a great importance. These two factors become more or less important depending on local environmental conditions. The general trend illustrated in **Figure 2.2.1** confirms the presence of economies of scale in consumption of wood for domestic use varying the household size. The main reasons explaining this phenomenon are:

(i) Fuel consumption per unit of food cooked decrease as batch size increase. This is supported by a study on comparison between different type of stoves which argues that fuel efficiency and heat transfer tend to improve as the quantity of food cooked increase [33]. This phenomenon has been noted previously by Fleuret & Fleuret (1978). In their study is suggested that the inefficiency of semi-open fires renders it more efficient to cook large quantities of food than small because the additional quantities are cooked by heat that otherwise would go to waste [27].

(ii) There is a fixed level of energy necessary to sustain a household. Hosier, in one of his studies on domestic energy consumption in Kenya, sustains that "there is a minimum quantity of energy (wood) necessary to absolve the main domestic need (like cooking, water heating and space heating) such that each additional member increases fuel consumption less than the previous" [27].

In conclusion, when the households' size increases, despite the total consumption grows the per capita one diminish because of econimies of scale.

2.3 Ease of access

This section, investigates the relationship between the ease of access to traditional biomass resources and their rate of consumption. The ease of access is composed by many aspects, such as sources distance, paths hardship, biomass availability – both in terms of quantity and density – and it has consequences on people's consumption pattern. In fact, this driver influences preferred sources, choice of collecting or purchasing, energy cost, and time involved in the gathering task. Those aspects will be hence analysed and explained in detail in order to derive general conclusions.

2.3.1 Literature analysis

The literature analysis of sixteen different papers concerned with the ease of access to biomass resources led to the definition of two main proxies for this driver, namely: biomass sources distance and density. In this sub-section both this elements are considered and illustrated.

The distance that households have to cover in order to reach biomass sources influences the shares of biomass collected and purchased. In Figure 2.3.1 [6], it is possible to see how, at the increase of the length of the path to be covered, the percentage of wood obtained by collection decreases, and to compensate, purchased wood increases.

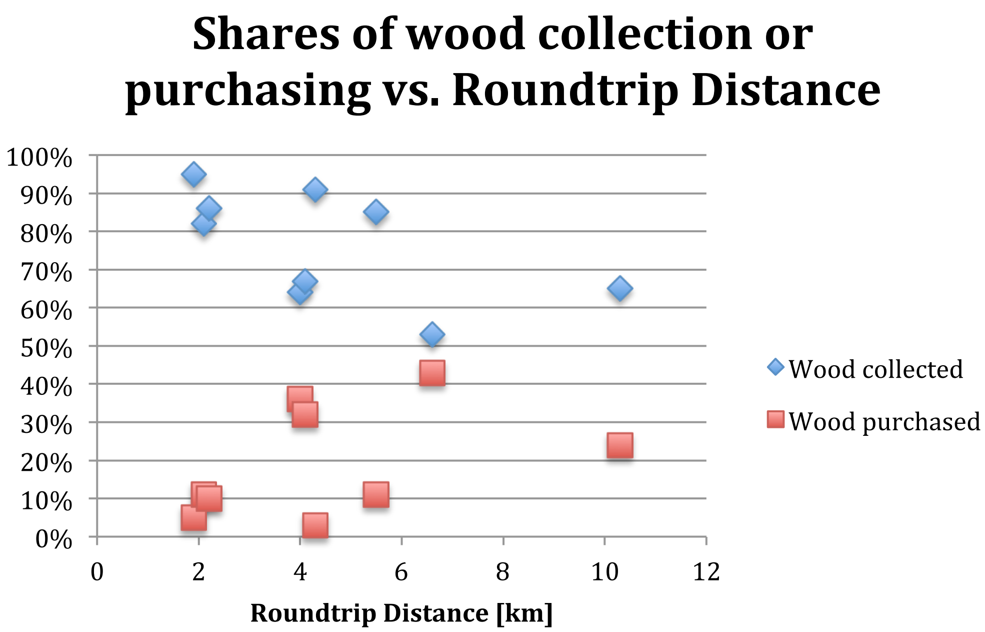

Figure 2.3.1 - Shares of wood collected or purchased in function of the collection distance [6].

Further considerations on the impact of distance can be derived from Figure 2.3.2 [10]. The figure shows a trend of biomass consumption that is at first decreasing with distance, according with the previous consideration, but increasing again when fuel wood is 3 km far or more from villages.

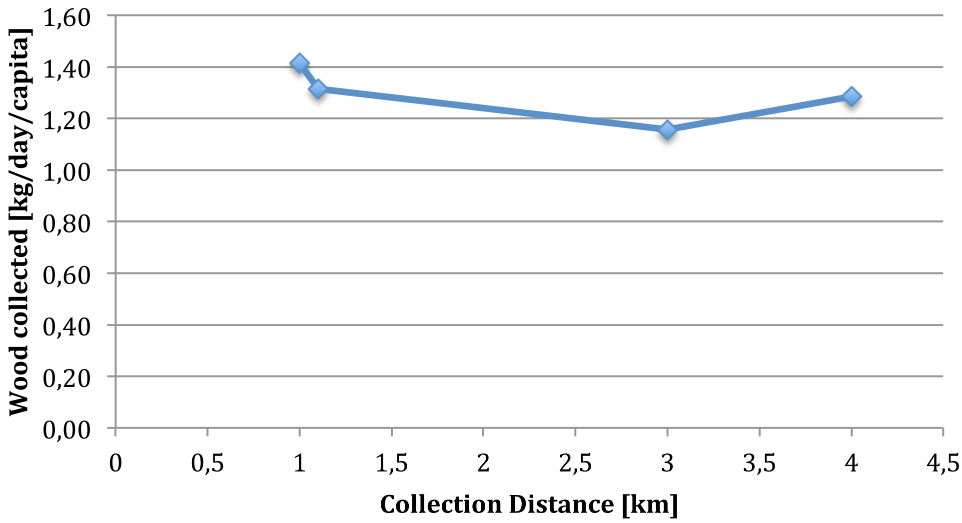

Figure 2.3.2 - Amount of wood collected in function of the collection distance [10].

It is possible to explain this tendency, common in different locations, considering a pattern described in several studies [10], [25], [34]–[37], where it is said that, in order to cope with the increasing collection difficulty, after certain distances households switch to lower quality wood, such as not preferred species (*i.e.* bushes, smaller pieces, branches, twigs, wet wood, dry leaves, etc.) and due to the poorer burning quality, a bigger amount than is necessary, as compared to wood of good quality.

Biomass availability is also dependent on biomass density and deforestation level. Data of fuel consumption, biomass density and biomass availability at different distances from two different villages in South Africa are reported [38]: in Athol the amount of biomass available and its density (kg per unit area) is higher close to the village and very far, but lower in the mid distance, the opposite happens in Welverdiend. The effect of the situation described is that, since the collection takes place near to villages, it is easier for Athol resident to access the resources, thus its inhabitants have a higher collection rate that those of Welverdiend. However the inhabitants of Welverdiend does not affect their consumption reducing need's satisfaction, but simply adapt their behaviour compensating by purchasing wood.

With data from Zimbabwe [39], it is possible to draw Figure 2.3.3 and give some conclusions about this issue. As deforestation level increases, the number of people using only fuel wood decreases, and more people have difficulties in accessing fuel wood to fully satisfy their needs, thus the number of people reporting having sufficient supplies tend to decrease. As a response, people satisfy biomass needs with agricultural residues, less preferred but allowing them not to suffer from energy scarcity. In fact, as noticeable, between very high and high deforestation levels, the percentage of people reporting sufficient supplies grows, as they switch to other fuels.

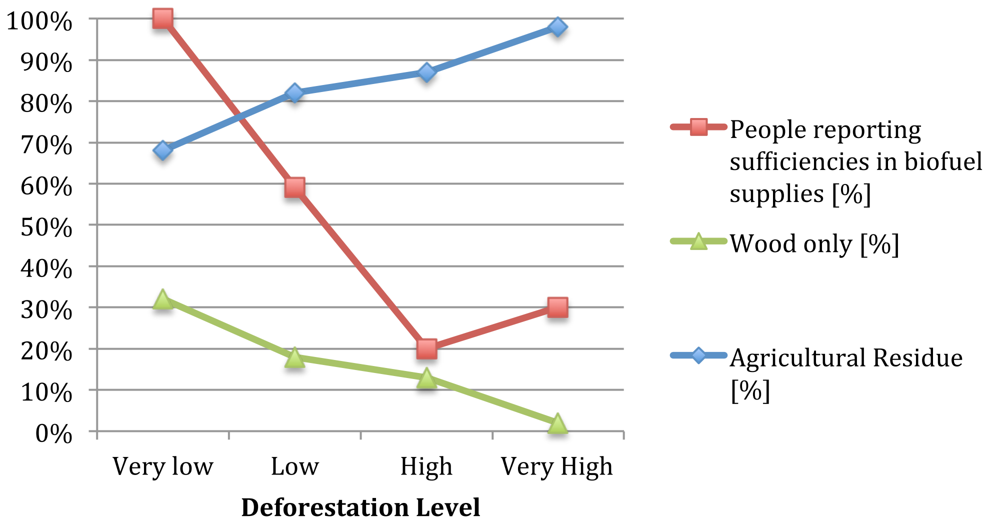

Figure 2.3.3 - Biomass data in function of deforestation level [39].

When the access to biomass energy sources becomes harder, householders start adapting their behaviour to the new situation in many different ways. The one largely reported in literature is the increased time ([10], [15], [16], [34], [35], [40]), distance ([7], [10], [16], [25], [34], [37], [40]–[42]) and thus labour ([43]) spent on collection. Gathering trips become longer, but their frequency lower ([16]). People begin to rely more on markets, increasing the share of biomass purchased on the total energy use ([16], [25], [39]), and as mentioned above they switch to less preferred biomass type. Finally, as fully described in the nutritional habits section 2.4, families adapt their cooking stiles in order to save energy ([16], [34]–[36], [39], [41]).

2.3.2 Critical analysis

Few reliable data on this driver were present in the scientific literature. Accordingly, it was not possible to perform a precise a quantitative study. A fundamental source was the paper "Rural household energy consumption in the millennium villages in Sub-Saharan Africa" [6], investigating energy behaviour of villages from "millennium villages project", granting accurate data from many rural settlements spread in different country of SSA; other interesting sources were [10], [39].

"Rural households in conditions of scarcity adjust their immediate fuel wood consumption profiles to mitigate the social impacts on their livelihoods" (Dewees, 1989) [16]; results of our literature investigation tend to confirm this finding. In fact as seen above, at the increase of difficulty in resource access, people try to compensate by purchasing, by switching to less preferred biomass type, and with a series of expedient to increase energy efficiency in their daily behaviour.

2.4 Nutritional habits

Traditional biomass is the main cooking fuel in almost all developing countries, so nutritional habits and the food sector have a big impact on fuelwood consumption. We expect that the more food is consumed the more wood is needed; consequently, food demand and nutritional habits should be a driver of biomass consumption. Furthermore, moving up the food production chain, the quantity of agricultural land and the way in which it is used also influence biomass availability. In particular, the increasing demand of agricultural land cause the removal of vegetation, that is often burnt on site, and consequently has a great impact on land degradation [10].

Households cooking practices still have a great importance. People believe that the best flavour of food is only achievable by means of traditional methods and for this belief any attempt to induce a switch to different cooking fuels find local's resistance. The same reason constitutes an obstacle in abandoning inefficient habits that are ingrained in traditional cuisine [40], [44], [45]. The diet also influences energy consumptions, because variations of number of warm meals consumed in a day and what is eaten comport variations in fuel needed [10], [23], [46].

2.4.1 Literature analysis

Object of this sub-section is to investigate on what is principally cooked, how it is cooked and which of these habits need more energy than others. The literature analysis we performed for this specific driver is based on four study sites, two located in East/Southern Africa (Botswana and Kenya) [7], [25], [36] and two located in West Africa (Mali and Nigeria) [15], [23], [28]. Nutritional habits and wood consumption of study sites are reported below. To avoid the influence of urbanization, charcoal use as cooking fuel, and atmospheric temperature of the sites we refer to rural data of wood consumption for the only needs of cooking and water heating.

For the case of Botswana, results refer to a national study based on field studies [7]. Eating habits contemplate 3 main meals with the following typical diet:

- Breakfast may include tea, bread, eggs, vegetables, Magwinya
- Lunch may include Bogobe, beans, meat, rice, Paleche, Madombi, vegetables
- Dinner may include Bogobe, tea, bread, meat, rice, Paleche, Madombi, vegetables.

Where local products are:

- Magwinya, a kind of cake made with plain flour.
- Bogobe, a kind of porridge with fuits.
- Paleche, a corn meal cooked to form a hard porridge served with meat or vegetables.
- Madombi, a bread eaten with stew and vegetables.

Almost in all cases all members are present for eating the meals because, especially in rural zones, they don't go far away for their daily activities. Consequently, food is prepared always for a lot of individuals and this promotes economies of scale analysed in the paragraph on family size 2.2. About half of the households interviewed cooks in apposite sites in front of home. These are square buildings with walls high two meters which sometimes have a roof. Walls are made by corrugated iron sheets or by mud while roofs are constituted by grass or by corrugated iron sheets. The main cooking fuel is wood and it's used just one active fire. Boling meals is the most common method of cooking but often these practice is substituted by frying and steaming. Surveyed households know energy saving techniques such as reduction of height of grate, use of wind shield and quenching of fire after use. However, others techniques like splitting firewood in small pieces or using very dry wood are not very practiced. There are also some efficient methods of cooking that are quietly known, such as use of a pot lid or slicing food into small pieces, monitoring of heat during cooking and soaking of food overnight. More than half of population is favourable to use improved stoves and as the income increases people begin to prefer gas cookers and electric stoves. However, this kind of cooking devices is diffused principally in urban centres while in rural areas households continue to rely on wood. Though the level of awareness on good practices is high, often people don't practice them, especially where wood is abundant. Annual per capita wood use in rural areas amount to 1157.74 kg, that is equivalent to 3.17 kg/day*cap. We have to consider that these values contemplate cooking (50%), water heating (25%) and space heating (25%) [7]. To make values more comparable with other case we could estimate a fuelwood consumption reduced by 25% linked to space heating, obtaining an amount of 2.4 kg/day*cap.

For the case of Kenya, results refer to two studies based on surveys conducted in rural and urban districts of Kenya [25], [36]. Almost all families cook 3 times per day for a total of 2-3 hours but there are also cases in which cooking take 3-4 hours of time per day. Maize is the main crop and considering that agriculture is mainly for subsistence it is also the base of locals' alimentation. Generally, unshelled maize and maize flour based meals are the most common dishes cooked in Kenya [36]. Most diffused local products are [36]:

- Ugali, a pasty substance made by stirring corn flour in boiling water.
- Githeri, a whole-grain food which consists in a mix of maize beans and vegetables that is characterized by requiring long period of boiling.

Firewood use in urban areas is very low and it is limited mainly to barbecue. Only very poor people use it as cooking fuel while most of urban households prefers charcoal. On the other hand, in rural areas, which we chose to focus on, wood remains the most used cooking fuel. Cooking with two fireplaces simultaneously is a common practice that is often required to prepare food combinations or more foods at the same time [25]. Some fuelwood saving strategies are also practiced in Kenya [25]:

- Adapt mode of cooking, frying foods that used to be boiled
- Use of wood and cow dung in a synergistic fashion for cook food that requires a lot of time. Dry cow dung is placed around the pot on the back of it while a few fuelwood sticks are fed in from the front.
- Soaking food in water when meals need a lot of fuel and time to be cooked.
- Quenching fires with water and retrieving half-burned firewood for use it later.
- Glowing embers from burned fuelwood for water heating, space heating or warming food.

Average firewood consumption is of 2.14 kg/day*cap in rural sites [36] but it's necessary to account that these values don't consider seasonal variations and include for some of the household the space eating contribute. Consequently, they may be a bit overestimated when compared to values of other countries.

For the case of Mali, results refer to a study conducted in a rural village of Mali, where field studies were accompanied by interviews and surveys [15], [23]. Household cook three times a day and meals usually include:

- Porridge, prepared with corn or millet or rice and a sauce prepared with leaves or peanuts or okra
- Couscous and steamed rice
- Peanuts and shea products [23].

Many families are polygamous and each woman has her own kitchen and stoves. They prefer stoking a large fire that will not smoulder while they are gathering water or preparing ingredients. Meals are commonly cooked in an enclosed kitchen or outside during hottest days and they require usually one fire or sometimes two. To start the fire women can use a butane lighter with straw or with plastic or trash otherwise they take burning embers from another cooking fire. Owning more than one stove is very common; all families have a three stones fire, used for all cook applications, and many of them own also an ICS, only used for smaller meals. In rural settings, households consume 0.54 kg/day*cap of wood for cooking, 0.23 kg/day*cap for water heating, 0.026 kg/day*cap for roasting peanuts, 0.006 kg/day*cap for making tea, 0.19 kg/day*cap for space heating, 0.028 kg/day*cap for shea processing and 0.01 kg/day*cap for making medicine [15]. Therefore, neglecting space heating and making medicine, wood demand is 0.83 kg/cap*day.

For the case of Nigeria, results refer to a study conducted in rural and urban areas of Ile-Ife, in Nigeria, where an annual survey took place [28]. Households cook meals 2.55 times in towns and 2.28 time in rural every day of the week and average time spent for this activity is of 2.6 hours per day [28]. Popular foods are:

- Gari, a typical food made from cassava tubers.
- Rice and beans with the addition of palm oil.

In urban households cooking is done inside the house in a separate kitchen without chimney so smoke escapes from windows and doors. In rural households cooking is done outside in places that may have roof or not. Dry wood is always used, and in rainy season wood is stored under covers. Method of cooking is generally the same everywhere in the considered region.

- Before starting a fire, the stove is cleaned of ash and wood residues
- Crop residues, paper and charcoal are usually used to lit the fire
- Crop residues are also used to maintain the fire but they are never used as principal fuel.
- Finally, the fire is always extinguished with water.

Kerosene is a very common cooking fuel in cities, where households own specific stoves, while in rural areas almost 100% of households rely on wood for cooking and continue to use the traditional three stones fire. In rural settings, wood consumption is 398 kg/year*cap that correspond to 1.09 kg/day*cap [28]. This rate of consumption corresponds to wood demand for all household needs but it must be considered that in the site of study space heating isn't required. So it can be approximated to wood demand for the only cooking and water heating activities.

2.4.2 Critical analysis

Data and information from the literature analysis are hereunder critically discussed, trying to highlight the impact of diet and cooking practices on wood consumption. A list of food features influencing fuel demand and a list of practices improving efficiency of cooking systems are drawn up. These could be interesting guidelines for interventions which aim at reducing consumption of wood for cooking.

Features of diet affecting consumption

Different studies have investigated on which meals are more energy expensive and on which are the food characteristics that cause an increase in fuel consumption. Their results can be summarized by defining a list of variables affecting consumption of wood:

- *Mass of dry ingredients*: it is the principal factor and it is obviously proportional to consume [23];
- *Presence of whole-grain meals in traditional diet*: this kind of food requires high consumption of fuel because it requires long time of water boiling. From studies emerges that a household cooking Githeri (a typical whole-grain food) consumes 1400 kg/year more than one who relies on non-whole-grain diet, for example a corn-flour meals like Ugali [36];
- *Prevalence of ground maize or unshelled maize in traditional diet*: meals based on unshelled maize use a double quantity of wood respect to ground maize meals. (1kg of unshelled maize requires 1.9 kg of wood while 1 kg of ground maize requires 1kg of wood) [46];

- *Size of grain flour*: reducing this size causes a reduction in cooking time and so in wood used [23];
- *Prevalence of maize or animal meals in traditional diet*: as households move from animal product based diet to a maize based diet, fuelwood demands increase [46];
- *Prevalence of legumes or vegetables in traditional diet:* it's observed that as the fuel become scarce people substitutes beans with vegetables. This is a consequence of high energy demand of food likes beans that need to be cooked for long time [34];
- *Presence of sauce in the meal*: meals with a component sauce require more energy than meals without sauce [23]. Grain and sauce type are not relevant variables after accounting for others factors [47].

Based on what said about features of diet affecting consumption, it appears that the typical diet of the two East/Southern African countries is more energy-consuming than that of the two West African countries. The determinants of this difference are:

- A diet based mainly on maize for Botswana and Kenya opposed to a diet based mainly on rice for Mali and Nigeria.
- A greater presence and importance of legumes in the diet of East/Southern African sites.

Summing up, meals consumed in Kenya and Botswana are characterized by longer cooking times and therefore they result more onerous from an energy standpoint. The chart in Figure 2.4.1, which we derived from the available data, seems to support those considerations, showing an average consumption significantly higher for West African sites.

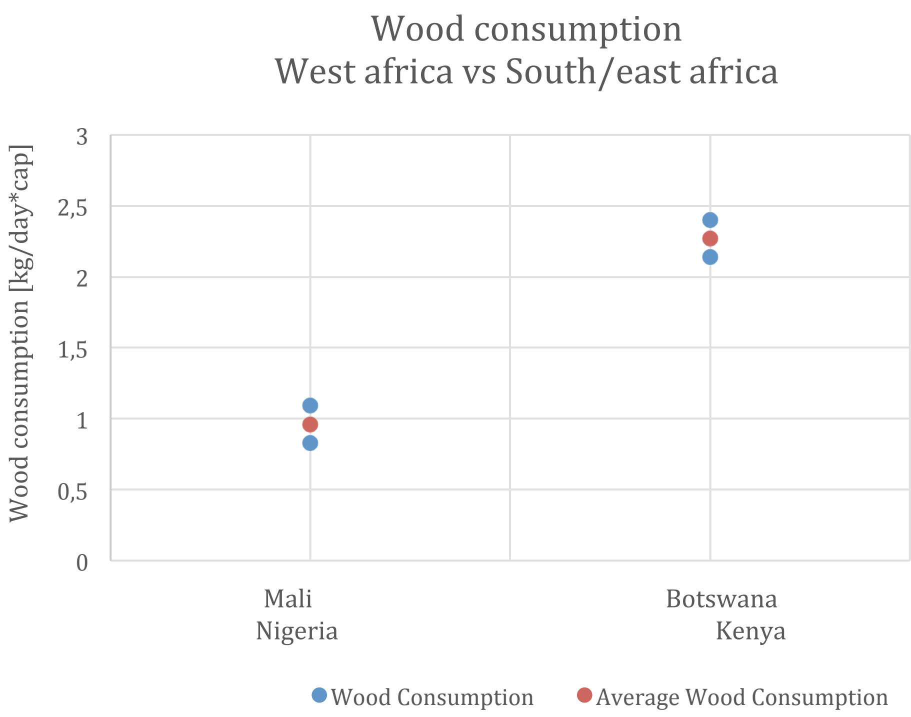

Figure 2.4.1 – Wood consumption of study sites divided by geographical area [7], [15], [28], [36].

We think that this situation could occur on a larger scale for the majority of the countries of East/Southern Africa, which have a diet based mainly on maize foods that require long cooking times, and for most of West Africa countries, which are less characterized by this kind of meals [48]. However, we think that this analysis, being base on results derived from few local studies, is not strong enough to affirm that wood consumption is determined by diet and consequently it could bring to erroneous conclusions. In this sense, there is a strong need of studies that investigate on nutritional habit and their impact on required amount of cooking fuel. We can affirm that type of meals surely influence consumption varying the amount of energy needed for cooking, but this remains a secondary variable as compared to other drivers that are more important. The diet factor remains something too variable and uneven, hence we can reasonably assume that macroscopic factors such as area of residence, seasonality and environmental/socioeconomic context can lead to far greater differences than the transition from one kind of meals to another. We have not drawn any conclusion on the influence of frequency of cooking because in every site analysed people were found to cook almost three times per day, preventing us from the chance for a comparative analysis. However, it is reasonable to assume that consumption is proportionally to frequency of cooking activities.

Efficient cooking practices

Some practices can influence fuel consumption increasing efficiency of cooking systems. Different studies have investigated on these practices trying to understand if they are known by people and if they are part of people habits. Their results can be summarized by defining a list of efficient practices:

- *Use of dry wood*: the LHV of dry wood is much higher than the LHV of wet wood, consequently it is required a minor quantity of wood to provide the same energy [7];
- *Use of wind shield:* this practice reduces thermal losses, limiting the convective heat exchange with the environment, and so it improves efficiency [7];
- *Use of a pot lid:* this practice reduces thermal losses, limiting the convective heat exchange with the environment, and so it improves efficiency [7];
- *Number of active fires:* using two fires increases energy use of 26% respect to one active fire [23];
- *The stove type*: every different type of stoves is linked to a different specific fuel consumption. This parameter, defined as the quantity of fuel needed to cook a given amount of food, is a measure of stove efficiency [47]. ICSs usually decrease consumption while traditional stoves, as three-stones fire, are usually characterized by lower heat exchange efficiency and consequently require more fuel. However, according to several studies [23] not all the ICSs are an improvement respect the traditional three-stone fire.

These technologies should be tested on field because laboratory results could conduce to incorrect results [23];

- *Family size*: as mentioned in section 2.2 on family size, larger families have a per capita consumption that is lower than smaller families. Generally, we can say that cooking for many people is more efficient;
- *The ignition method*: use of burning embers reduce energy consumption of 10% [23]. This is a recovery technique which allows to avoid the energy expenditure for the ignition of a new fire;
- *Quenching of fire after use*: this practice prevents waste of fuel [7] and give the possibility of retrieving half-burned wood [49];
- *Slicing of food into small pieces:* this practice reduce time of cooking and so demand of energy [7];
- *Cooking in least amount of liquid*: this practice reduce time of cooking and so demand of energy [7];
- *Soaking of food overnight*: this practice reduce time of cooking and so demand of energy [7];
- *Reduction of the height of grate*: this practice improves efficiency of thermal exchange [7];
- *Splitting firewood into small pieces*: this practice improves combustion efficiency [7].

It is difficult to estimate the weight of these practices on fuelwood consumption. It is arguable that these strategies have a limited weight compared to other drivers of consume. Nevertheless, they certainly lead to a more efficient use of the resource and for this reason awareness of locals over them should be increased.

2.5 Urbanization and the role of charcoal

Several studies on wood-fuels (firewood and charcoal) in DCs indicate the following pattern: total population using firewood is constantly declining while there is an increasing adoption of charcoal as the main cooking fuel [50]. Urbanization is the major driver for the transition from firewood to charcoal, so charcoal is identified as the "transition fuel" to which fuelwood users are most likely to switch in urban areas [50]. This transition is the most important in fuel switching patterns actually in action for the residential sector in Developing Countries. In quantitative terms, for the case of Uganda, charcoal consumption increases at a rate close to the urban growth rate of 6% per annum (MEMD2007), underlying a possible association between these two phenomena. Furthermore, the percentage of households using charcoal is much higher in towns than in rural areas and in the same way the percentage of people relying on firewood is much higher in rural than in urban areas [50].

However, the switch from wood fuel to charcoal does not necessarily entail a reduction in the total biomass resource consumption, as charcoal production is based on woody biomass as a primary input. The indirect consumption of woody biomass should be thus carefully considered when discussing charcoal use. We consider at title of example the following case study from Uganda. The Renewable Energy Policy for Uganda (REPU) indicates that in 2006, Uganda had a per capita consumption of 680 kg/year and 240 kg/year for firewood, and 4 kg/year and 120 kg/year for charcoal, for rural and urban respectively (MEMD2007). A simple addition would give a total of per capita wood-fuel consumption of 684 kg/year for the rural and only 360 kg/year for the urban. The conclusion would be that the rural households consume twice as much quantity of wood-fuel as the urban counterpart. However, if the accounting is done with respect to the feedstock used for charcoal production, the picture gets reversed. Taking a reasonable conversion factor of 10 [50], the wood for charcoal would be 40 kg and 1200 kg for rural and urban households respectively. Adding firewood, the aggregate wood for the total primary energy consumption for rural and urban households would be 720 kg and 1440 kg, respectively. So the urban households that predominantly use charcoal for cooking require twice as much primary energy from wood as their rural counterpart. Consequently, every person making a transition from using firewood to charcoal for cooking purposes requires twice as much quantity of wood harvest. As a result, urbanization, being a major driver for charcoal consumption, might be also responsible for the rapid depletion of biomass resource.

2.5.1 Literature analysis

This analysis section considers a set of twenty-four studies in order to derive data on consumption rates of wood and charcoal in rural and urban areas of different African countries. However, the discussion of these results requires a preliminary analysis of charcoal and its features; in particular: the lower heating value (LHV), the efficiency of production processes and the selling price of fuel. Those parameters are here discussed in order to highlight the relationship between charcoal use and primary biomass consumption.

2.5.1.1 Charcoal supply chain

Charcoal is a light, black residue, mainly composed by carbon and ash, obtained removing water and others volatile constituents from biomass. It is usually produced with pyrolysis, a process of heating wood in absence of oxygen.

The Purpose of this section is to identify in literature parameters which are useful to evaluate the impact of charcoal on natural resources and the reason why households choose this fuel in urban areas. It was decided to not consider the factor related to cooking stoves because it was found that charcoal stoves have only a little higher efficiency compared to wood stoves, so this aspect does not determine variations of impact between a fuel and the other [14], [51]. Below it is reported a table with values of LHV found in different studies. The last raw of Table 2.5.1 report an average value of LHV that we have calculated by an arithmetic mean of those values.

Lower Heating Value of wood [MJ/kg]	**Lower Heating Value of charcoal** [MJ/kg]
14.8	29.1
15.5	29
14	-
18	31
15.5	29
14.8	29.7
Average LHV of wood	**Average LHV of charcoal**
15.43 MJ/kg	29.56 MJ/kg

Table 2.5.1 – Lower Heating Values of wood and charcoal in literature [15], [19], [22], [36], [52], [53].

These values do not always respect the scientific definition of LHV[1] and the methods by which they were obtained are multiple. In the first study [15], lower heating value of wood and charcoal was determined using a weighted average of woods and moisture contents detected from samples gathered on field and accounting seasonal variation and preferred wood uses. In the second study [52], heat value is considered as a fuel efficiency where output is energy (MJ) produced by combustion and input is mass (kg) of wood required. In the third study [53], it is reported that net energy available from biomass when it is combusted ranges from

[1] Lower Heating Value of a fuel, at standard conditions, is defined as the heat extractable from a closed system, in which the products of a full combustion are reported to the initial standard conditions; assuming that all the water present in them is in the vapour state [70].

about 8 MJ/kg for green wood to 20 MJ/kg for dry plant matter. In Table 2.5.1 is reported a mean value of these two. In the fourth study [36], it is assumed that 1kg of air dry wood contains 18 MJ of energy while 1kg of charcoal contains 31 MJ of energy. Biomass Energy Strategy of Malawi [19] assumes, as energy values, 15.5 MJ/kg for air dry firewood and 29.0 MJ/kg for charcoal. In the sixth study [22], a lower heating value of 14.8 MJ/kg was determined using a weighted average of woods and moisture contents that account for seasonal variation and preferred wood uses. Similarly, a lower heating value of 29.7 MJ/kg was used for charcoal.

There are several different processes to obtain charcoal from wood and the efficiencies of such methods are crucial to investigate the impact that the use of charcoal has on wood resources. Table 2.5.2 lists all the processes found in literature and groups them in traditional and modern methods, reporting an average efficiency for these macro categories.

Production Method	**Efficiency**	**Range** [min-max]
Traditional Methods	15.4 %	
- Dripping water over embers	10.6 %	2.5 - 29.0 %
- Chipping away char layer from burning wood	23.7 %	21.7 - 25.7 %
- Carbonization	12.5 % 15.2 %	8.33 – 16.67 %
- Earth-Mound Kilns	15 % 13 %	14 - 16 % 12 - 14 %
- Pit Kilns	17.5 %	15 - 20 %
Modern Methods	29.5 %	
- Improved Kilns	25 %	

- *Casamansa* - *Stationary Brick Kiln* - *Transportable Metal Kiln*	18 %	
- *Modern Kilns* - *Retorts* - *Bee-Hives* - *Mark V*	35 %	
- *ICPS*	40%	35-45%

Table 2.5.2 - Production methods of charcoal [14], [15], [54]–[58].

Two common methods used to produce charcoal are: dripping water over embers after cooking, in household cooking fires, or chipping away the char layer from burning wood, in blacksmith controlled above-ground fires [15]. Another pyrolytic process for charcoal production is carbonization. It is a traditional method based on use of covered pits into which wood is piled, burned and covered with earth mounds. Control of the reaction is often crude and relies heavily on experience. On a weight basis, from 6 to 12 tonnes of wood are needed to product a tonne of charcoal. So efficiency varies between 8.33% and 16.67%, which average value is of 12.5% [54]. FAO considers a theoretical carbonization ratio of 6.6 tons of wood to produce 1 ton of charcoal, which is equivalent to an efficiency of almost 15.2% [55]. On the basis of this principle, a traditional technology for charcoal production is the earth-mound kiln. This type of kiln takes four to seven days to produce charcoal and has a low efficiency (around 15%) because of unpredictable fire and heat loss through radiation [56]. Mozambique BEST of 2012 [57] also considers earth-mound kilns, locally designated as boat-like. This type of kiln has an efficiency of 14% when wood is arranged longitudinally or 16% when wood is arranged transversally. Steps for charcoal making with earth-mound kilns are also described:

1. locating suitable trees
2. choosing a good place to build the kiln (flat and sandy soils near to trees)
3. cutting trees and transporting them to kiln site
4. gathering material necessary for kiln construction (grass, clay/sand, stones)
5. constructing and operating the kiln
6. unloading the kiln and putting charcoal into sacks

On this base, improved kilns (Casamansa) have been experimented yielding an efficiency of 18%. This type of kilns, rectangular with one or two chimney, shows a little increase in efficiency at cost of an increased labour demand and consequently is not very diffused. Other improved kilns are stationary brick kilns that are semi-permanent structures and transportable metal kilns that could be useful for decentralized charcoal production. In average it will be possible to obtain kiln efficiencies of 25% in case of improved types. Improved Charcoal Production Systems (ICPS) is a type of kiln tested in different sites, giving a lot of good results as: efficiency of 35-45%, calculated on dry weight, low emissions of CO and others pollutant species during the process and processing time reduced to only 10 hours [57]. Pit kilns is a very simple type of kilns used in Gourma region and generally diffused in Sahel which efficiency varies between 15 and 20%, as reported by Von Maydell in 1983. Pit kilns are built digging a pit in the ground and have to be used several times to be worth the effort [58]. National Energy Policy for Malawi of 2003 [14] report thermal efficiencies of 12-14% for traditional earth mounds while efficiencies are much higher (around 35%) for modern charcoal carbonisation kilns (for example, Retorts, Bee-Hivers, Mark V). It is interesting to consider that the impact of increased efficiency on productivity is non-linear: an efficiency increase from 15% to 28% corresponds to a productivity increase of 86%. In addition to a higher efficiency, optimization of carbonization technologies improves quality of charcoal produced, reduces emissions of pollutants and reduces production time. So adoption of improved kiln technologies is highly desirable. However, higher material costs, increased labour input and lack of knowledge represents disincentives for charcoal burners to adapt improved technologies.

Despite the presence of illegal activities fuelwood market is quite organized and it involves multiple actors such as: rural wood sellers, fuelwood producers, transporters, wholesalers and retailers. Table 2.5.3 and Table 2.5.4 report the decomposition of mean urban retail price and costs of firewood and charcoal in Malawi [59].

Supply chain	**Cost** [MWK/ton]	**Selling price** [MWK/ton]
Raw wood	975	975
Production site	900	2175
Roadside	695	3480
Wholesale, town	2470	6215
Retail, town	0	8395
Total	5040	8395

Table 2.5.3 – Decomposition of mean urban retail price and costs of wood in Malawi [59].

Supply chain	**Cost** [MWK/ton]	**Selling price** [MWK/ton]
Raw wood	2790	2790
Production site	5377	9960
Roadside	1230	14520
Wholesale, town	4270	19800
Retail, town	0	28415
Total	13667	28415

Table 2.5.4 – Decomposition of mean urban retail price and costs of charcoal in Malawi [59].

The supply chain analysis show that:

- in absolute terms transportation costs more for charcoal, because of presence of corruption in this phase, as reported by [60];
- cost of raw wood is higher for charcoal because production of charcoal must consider a process of transformation which efficiency is less than 1, so to produce 1 kg of charcoal it is necessary more than 1 kg of wood;
- retailers have only the acquisition cost and so cost of retail is null.

2.5.1.2 Wood and charcoal consumption in rural and urban areas

Made this overview about charcoal, the analysis shifts the focus on consumption rates of different African Developing Countries. Table 2.5.5 and Table 2.5.6 summarize results on wood and charcoal consumption of different studies which are briefly presented below.

Country	**Rural Wood Consumption** [kg/day*cap]	**Urban Wood Consumption** [kg/day*cap]
Botswana	3.17	1.17
Cameroon	1.18	0.8
Ethiopia	1.63	0.44
Kenya	2.14	0.14
Malawi	1.65	0.8
Mali	1.61	0.75
Nigeria	1.09	1.03
Rwanda	1.03	1.04
Uganda	1.86	0.66
Zimbabwe	3.56	1.09

Table 2.5.5 – Consumption of wood in rural and urban areas of different African countries [7]–[9], [19], [20], [28], [36], [61], [62], [86].

Country	**Rural Charcoal Consumption** [kg/day*cap]	**Urban Charcoal Consumption** [kg/day*cap]
Cameroon	0	0.17
Ethiopia	0.19	0.35
Kenya	0.26	0.37
Malawi	0.02	0.26
Mali	0	0.33
Rwanda	0.31	0.39
Uganda	0.01	0.33

Table 2.5.6 – Consumption of charcoal in rural and urban areas of different African countries [7]–[9], [19], [20], [28], [36], [61], [62], [86].

For the case of Botswana, the focus is on fuelwood demand for household needs, so the principal thermal activities (cooking, water heating and space heating) are considered. End use data were derived from two comprehensive surveys conducted in 2000 and reported in a national study on Botswana [7]. To make an overview of rural and urban uses, measurements were undertaken in rural villages in all the ten Districts and for urban villages in five Districts in eastern Botswana. Results show that wood remains the main cooking fuel for rural households because of its great availability that make it obtainable for free. In urban areas charcoal, kerosene and LPG become more important and the per capita wood consumption decreases. Annual per capita wood use amount to 1157.74 kg and 428.62 kg in rural and urban areas respectively, which are equivalent to 3.17 kg/day*cap and 1.17 kg/day*cap. Data for charcoal were not detected.

As for Cameroon, the reference point is a study conducted by Njiti and Kemcha in Garoua Town and the rural area within a radius of 50 km from the town's centre [8]. Data were collected by survey with appropriate questionnaires in a number of sample villages and quarters. Results show that rural population is totally dependent on wood energy while urban households rely on a mix of wood and alternative heat energy sources. In rural areas all household surveyed justified their dependence on wood explaining that it is the only source of energy at their disposal and that it is gatherable for free. However most of them are aware of the risks that an overexploitation of this resource involve, so they are trying to control wood consumption. For the 1753 persons belonging to households surveyed wood consumption is 2073 kg/day. This gave an average consumption per capita of 1.18 kg/day*capita In urban areas household use a combinations of different sources of energy, nevertheless the share of fuelwood in these mixes is high and consequently they are also dependent on wood energy. The consumption of 3469 kg/day of wood by 4332 users and 120 kg/day of charcoal by 727 consumers gave an average use of 0.80 kg/day*capita and 0.17 kg/day*capita respectively.

For the case of Ethiopia, the reference is a study based on semi-structured interviews and elaborated in cooperation with the Ethiopian Ministry of Water and Energy [9]. For rural data the study considers nine major spatial units grouping Livelihood Zones, areas identified by the Livelihood Integration Unit of the Disaster Prevention and Preparedness Agency Early Warning Directorate. These areas are part of six regions in which urban data were collected. The most biomass energy uses are cooking activities, heating and lighting while any other use for small industries is considered negligible. In rural areas wood is the dominant fuel type above all where conditions are most suitable for tree growing while zones afflicted by shortage of wood register a lower wood consume. Recently, also charcoal is gaining importance. Considering the reported annual consumption for every region and operating a mathematical average, we have obtained a per capita daily consumption of 1.63 kg/day*capita for wood and 0.19 kg/day*capita for charcoal. For urban areas, the survey makes a distinction between large towns (over 20'000 people) and small towns. We can see that wood and charcoal are used by both large and small town households. Wood is purchased in both cases but in small towns families often gets it from communal lands and for this reason this fuel maintain is primary importance while in large towns its rate of consumption decrease significantly. In this case it is necessary to calculate the weighted average consumption, considering population of each region as weigh for the reported annual consumptions. Following this procedure, we have obtained a per capita wood consumption of 1.09 kg/day in small towns and 0.44 kg/day in large towns, and a per capita charcoal consumption of 0.27kg/day in small towns and 0.35 kg/day in large towns. For our purposes the relevant data are those related to large cities, even if it is interesting to observe that increasing the size of the urban centre there is a gradual decrease of wood use in favour of charcoal.

Data for Kenya were derived from a study of Kituyi and Marufu operated in selected sites of urban and rural Kenya is the reference of this paragraph [36]. They conducted a questionnaire in these areas to establish biofuel domestic consumption rates and patterns. Wood is the most used source, especially by rural families who gathered it for free from the surrounding environment and which consumption rates are consequently a function of availability. Contrariwise, in urban areas firewood is limited to poor households and so its consumption falls. For charcoal, use is much higher in urban then in rural areas because of its convenience while outside these locations abundance of firewood and high cost of charcoal explain its limited use. Wood consumption rates in rural areas ranged from 0.8 to 2.7 kg/day*cap yielding a weighted average of 2.14 kg/day*cap. While in urban zone it lays in the range of 0.01-0.5 kg/day*cap giving a mean of 0.14 kg/day*cap. We observe a range of 0.18-0.69 kg/day*cap, which weighted average is 0.37 kg/day*cap, in urban centres. While in rural zones charcoal use lays between 0.07-0.46 kg/day*cap for a mean of 0.26 kg/day*cap.

As regards Malawi, results are based on the “Malawi Biomass Energy Strategy” published in January 2009 [19]. In this report is present a big number of data derived by numerous surveys focused on household demand sector. Wood is clearly the country’s dominant fuel, followed by charcoal, which has become increasingly important, and crop residues. Most of urban households use more than one fuel for cooking but firewood remains the first choice for the majority of them while in rural areas household energy needs (principally cooking, warming water and heating) are satisfied almost exclusively by wood. The choice of firewood as primary fuel for thermal uses is due to the fact that, even when it is not gatherable for free, it remains the cheapest alternative. This is a reflection of low disposable income linked to a situation of poverty that is very common in Malawi. As a consequence, switching to modern fuels is very complicated. From data of Northern, Central and Southern regions it is obtainable a weighted average consumption of 292.92 kg/year*cap (equivalent to 0.8 kg/day*cap) for wood and 94.02 kg/year*cap (equivalent to 0,26 kg/day*cap) for charcoal in urban centres and a weighted average consumption of 601.1 kg/year*cap (equivalent to 1.65 kg/day*cap) for wood and 7.21 kg/year*cap (equivalent to 0.02 kg/day*cap) for charcoal in rural areas.

For the case of Mali, results are based on "Etude sur les professionnels du Bois Energie au Mali", a study focused on importance of wood as source of energy [61]. On the base of precedent studies, it reports fuelwood consumption for different rural regions: Kayes, Koulikoro, Sikasso, Ségou, Mopti Delta, Mopti, Gao and Tombouctou. The same study estimated use of wood and charcoal in the main cities located in these regions. For rural areas it is necessary to calculate the weighted average consumption, considering population of each region as weigh for the reported daily consumptions; we have obtained a per capita wood consumption of 1.61 kg/day*cap. While in urban areas average consumption result to be 0.75 kg/day*cap for wood and 0.33 kg/day*cap for charcoal.

For the case of Nigeria, we refer to a study conducted by Kersten et al. [28] in a tropical rain forest area, in South-West of the country. Survey takes place in two periods (dry season and wet season) and includes 1120 questionnaires. 680 were filled out in the town of Ile-Ife while 440 were from the surrounding rural area. In this study wood consumption was determined by weighting. Fuelwood use for domestic need was estimated to be 1.03 kg/day*cap for urban households and 1.09 kg/day*cap for rural families. In urban areas firewood is chosen by 23% of people as their cooking fuel while 64% chose kerosene that is the most important energy source in this compound. In rural areas almost 100% of households make use of wood and there is no interest in changing fuel because wood supply is unlimited and free.

As regards Rwanda, results are extrapolated from "Biomass use survey in urban and rural areas in Rwanda", a report prepared in collaboration with Energy Water and Sanitation Authority (EWSA) [20]. A survey was designed to collect information about rural and urban demand of different fuels and measures of weight and volume have been made to estimate these consumptions. Almost all rural households use wood fuels as their main cooking energy. It is interesting the high rate of charcoal use despite of the "urban nature" of this fuel. So it is not surprising that charcoal dominates in urban districts with rates directly proportional to standard of livings. Average annual consumptions of 1885 kg/year*cap for wood and 565 kg/year*cap for charcoal, are reported for rural areas. While in cities annual rates of consumption result to be 1891 kg/year*cap and 711 kg/year*cap for wood and charcoal respectively. Assuming an average family size of 5, it is obtained an average wood consumption of 1.03 kg/day*cap and 1.04 kg/day*cap in rural and urban areas respectively. While families consume 0.31 kg/day*cap of charcoal in rural zones and 0.39 kg/day*cap in cities.

For Uganda results are based on data found in 2007 by UBOS and Ministry of Energy and Mineral Development (MEMD) for the Government of Uganda [62]. Analysing consumption trends in rural and urban areas we can observe that urbanization is typically the major driver for transition to charcoal. Fuelwood consumption is greater in rural areas while charcoal use is higher in urban sites. As reported by the MEMD, Uganda has wood rates of consumption of 680 kg/year*cap (equivalent to 1.86 kg/day*cap) and 240 kg/day*cap (equivalent to

0.66 kg/day*cap), for rural and urban areas respectively. While charcoal rates of consumption result to be 4 kg/year*cap (equivalent to 0.01 kg/day) and 120 kg/year*capita (equivalent to 0.33 kg/day), for rural and urban areas respectively.

Finally, for Zimbabwe, data are extrapolated by a study conducted from January 2006 to March 2007 by Marufu [86], who used a methodology based on questionnaire survey and long-term monitoring. One of the aims of the study was to estimate the overall mean national rural and urban consumption rates of biofuel. Wood is the predominant fuel in rural areas while in urban centres electricity and kerosene are the preferred fuels with fuelwood playing a supplementary role. Consequently, we can assert that rural families are much more dependent on biofuels. Study results report a per capita consumption of 1300 kg/year*cap (equivalent to 3.56 kg/day*cap) for rural households and a per capita consumption of 400 kg/year*cap (equivalent to 1.09 kg/day) for urban households.

2.5.2 Critical analysis

Based on the previous analysis on consumption rates, some interesting observations can be drawn. As shown in Figure 2.5.1, derived from data presented in 2.5.1, rural areas are characterized by a higher firewood use in comparison to urban areas. Where this trend is not verified (Rwanda) values are very similar so do not constitute an evidence against. Great availability and the possibility to obtain it for free gathering it from surrounding areas are the main reasons which make wood the dominant fuel in rural areas. Low income and lack of alternatives are also determinants that need to be considered.

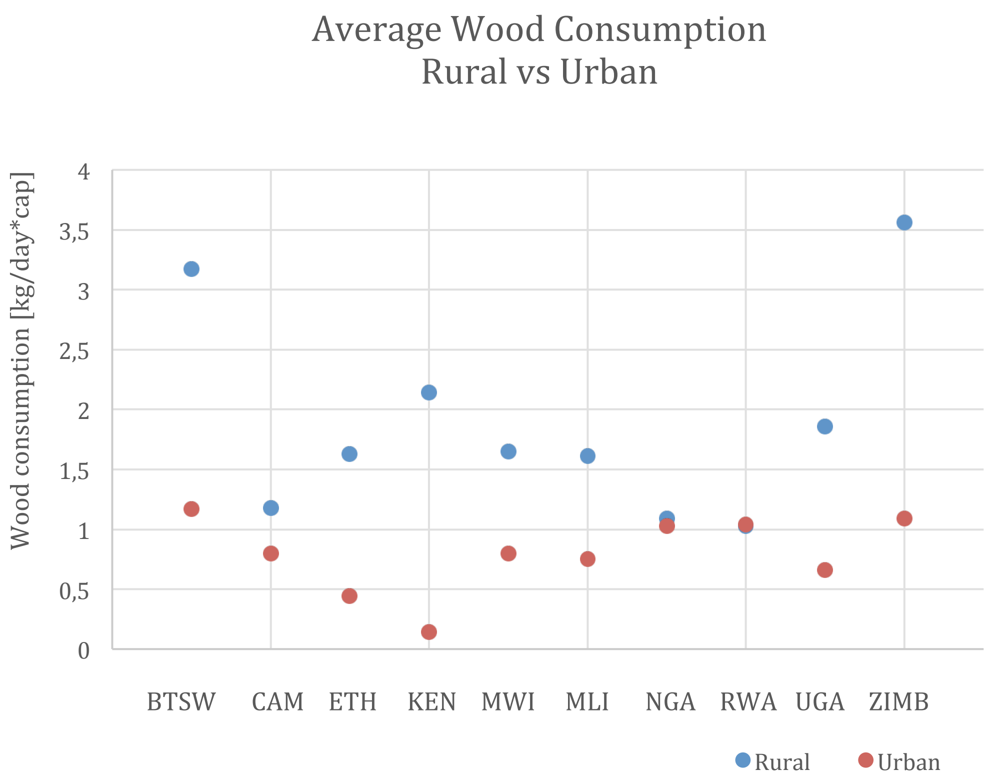

Figure 2.5.1 – Consumption of wood in rural and urban areas of different African countries [7]–[9], [19], [20], [28], [36], [61], [62], [86].

As shown in Figure 2.5.2, the situation for charcoal is specular to the previous; urban households use a quantity of charcoal which is significantly greater as compared to their rural counterparts. Charcoal is gaining importance in Developing Countries, especially in cities where it is substituting wood in the satisfaction of households thermal needs.

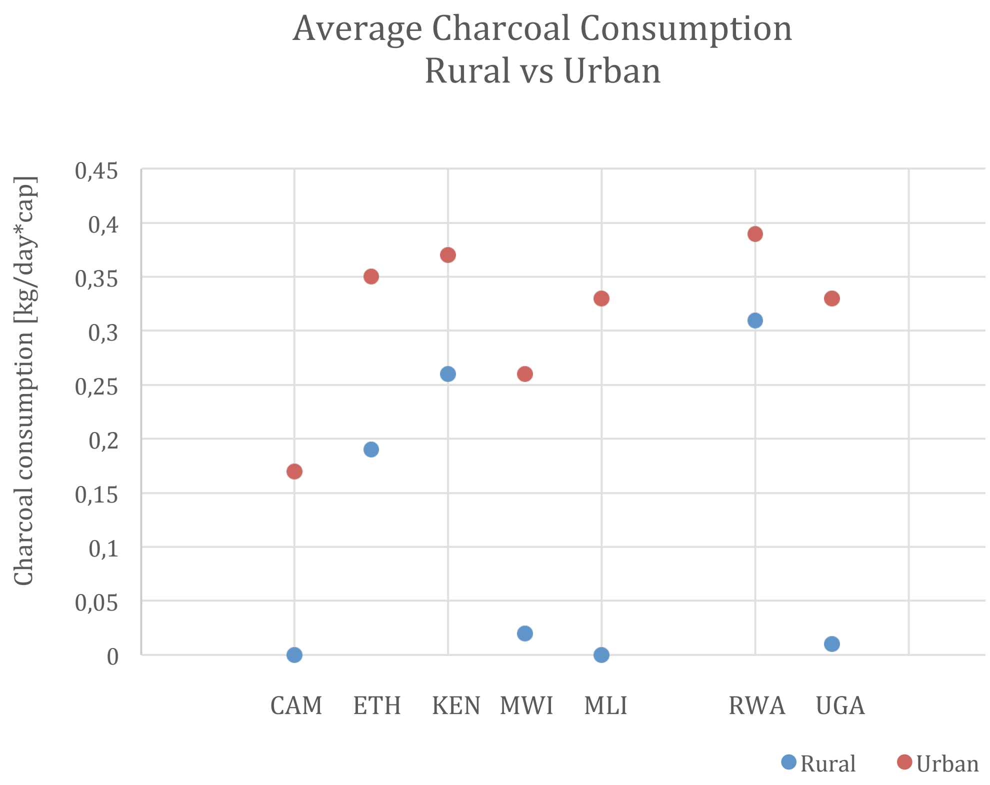

Figure 2.5.2 – Consumption of charcoal in rural and urban areas of different African countries [7]–[9], [19], [20], [28], [36], [61], [62], [86].

It is interesting to try to understand the reason why in cities households chose charcoal rather than wood. There are some arguments in favour of charcoal that make it preferred over firewood, especially in urban areas:

- It has a higher energy content per unit of weight. As seen previously, on the base of considered reference studies, average lower heating value (LHV) of wood and charcoal are respectively 15.43 MJ/kg and 29.56 MJ/kg. This means that charcoal as an energetic potential that is almost double compared to potential of wood and so people can burn a reduced quantity of fuel to satisfy the same need.
- As a consequence of the previous point, it is easier to burn in compact and portables stoves and it is easier to be transported to markets.

- It is cleaner, since it emits less smoke and polluting substances when used for cooking.
- As a consequence of previous points, it is more suitable for sites where the dwelling spaces are small.
- It is more convenient to handle and it is less subject to seasonal factors, such as humidity.
- It is not subject to storage losses due to termites and rot.
- It is economically attractive as firewood substitute when this last one is scarce and has to be transported over long distances.
- To satisfy domestic thermal needs is preferred over modern fuels, for cultural and economic reasons.

Another factor, which deserves a separate discussion, is the price of fuels. Considering data present in literature [59] and assuming average LHVs of 15.43 MJ/kg and 29.56 MJ/kg for wood and charcoal respectively, price per unity of energy was derived. Considered the different LHV per unit of mass of the two fuels, it is a better discriminant compared to price per unit of weight.

Supply chain	**Wood selling price** [MWK/GJ]	**Charcoal selling price** [MWK/GJ]
Raw wood	63.19	94.38
Production site	77.77	242.86
Roadside	84.58	153.96
Wholesale, town	177.25	178.62
Retail town	141.28	291.44
Total	544.07	961.27

Table 2.5.7 – Selling price for unity of energy of wood and charcoal in Malawi.

As shown in Figure 2.5.3, selling price of charcoal is significantly higher compared to price of wood. However, this gap decreases when prices are expressed per unit of energy (Figure 2.5.4): wood price referred to tonne is about one third (29.54%) of charcoal price while if it is referred to GJ it become about half (56.6%) of that. Even if mitigated, the difference between prices of the two fuels remains considerable. Consequently, the reason why urban households choose charcoal instead of wood is not connected to an economic advantage, indeed they are willing to pay more for this fuel. However, charcoal remains the cheaper alternative to wood in an urban setting when compared whit modern fuels.

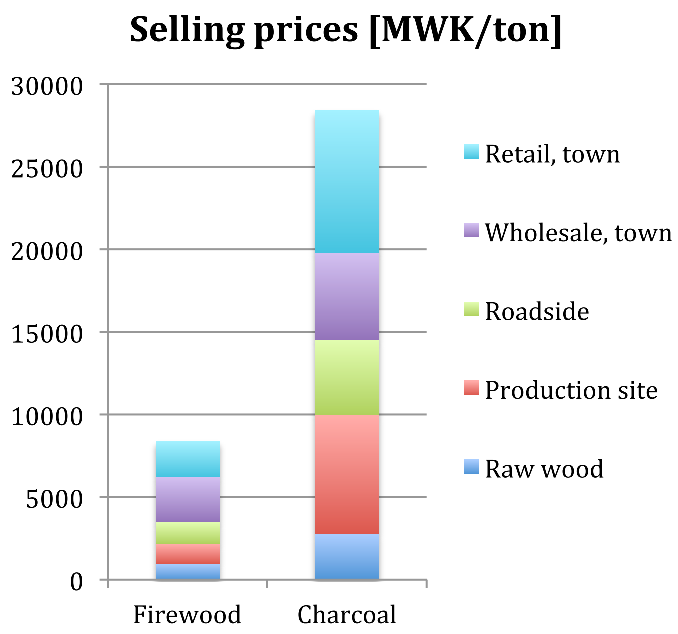

Figure 2.5.3 – Selling prices of wood and charcoal for unity of weight [59]

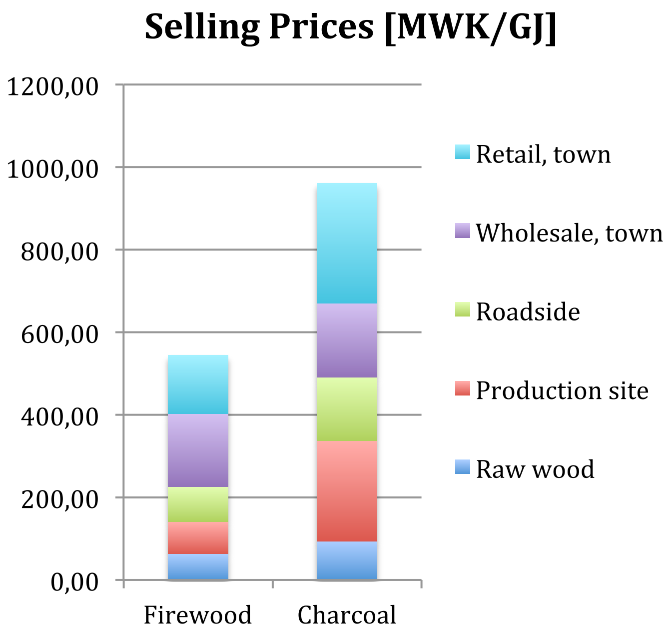

Figure 2.5.4 – Selling prices of wood and charcoal for unity of energy

Analysis ultimate goal is to estimate the impact of fuelwood consumption on primary biomass resources. From a rough account it might seem that, adding charcoal consumption to wood consumption, urban households consume less biomass than their rural counterpart. However, as shown previously, the production of charcoal uses highly inefficient processes and hence it will be necessary to consider the input amount of wood for a better estimate. Considering this, it was decided to use the average efficiency obtained in 2.5.1.1 for traditional methods of charcoal production (15.4%) in order to estimate the real consumption of biomass for rural and urban areas starting from data in Table 2.5.5 and Table 2.5.6. A graphic result of this operation is shown in Figure 2.5.5.

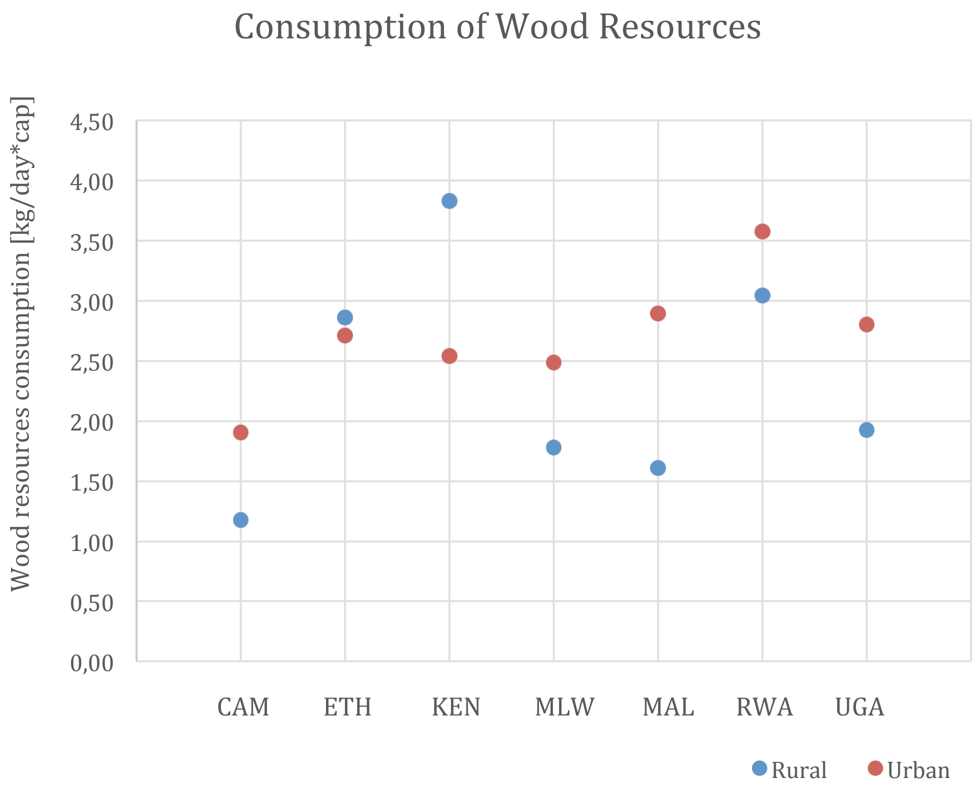

Figure 2.5.5 – Consumption of wood resources in rural and urban areas of different African countries

It is clear that the situation is quite different compared to that which would result from a simple sum of the consumptions of wood and charcoal. If above this sum gave a higher consumption in rural than in urban areas, now the situation is reversed. Kenya represents a clear exception that is probably due to the fact that also in the considered rural areas there is a considerable amount of charcoal consumption, while Ethiopia results show an irrelevant difference between the two values.

In conclusion, it emerges that urbanization, being one of the major drivers for charcoal use, increases the pressure on biomass resources leading to their overexploitation, especially in surrounding areas of large urban centres.

2.6 Economic background and fuel alternatives

In this section the consequences of income, access to grid and fuel alternatives on energy choices in DCs are investigated. Through a literature analysis, households' behaviours were studied and compared with the "energy ladder theory" and the "fuel stacking theory", and it is shown how the latter is the one that better represent the real case. Indeed people, once having economic possibilities and access to different energy sources, do not abandon completely biomass consumption for thermal purposes, but rather tend to associate its use with that of other modern fuels, such as kerosene, LPG and electricity for other uses, such as lighting.

2.6.1 Literature analysis

A literature analysis concerning the influence of household income on their fuel choice is illustrated. An interesting graph is in Figure 2.6.1, with data from rural area in Kenya [63], showing peoples' behaviour in terms of fuel sources for cooking, at increasing economic possibilities. It is possible to notice how, with the income growth, the amount of families using fuel wood remains at 100%: this means that no one chooses to abandon this source, although other fuels are used in combination with it. A considerable trend is that of the number of households with charcoal in their energy mix, growing from 31.6% among the ultra-poor to 66.7% between well-off families. Kerosene and LPG show similar patterns, being about zero except for the richest families, where they are used respectively in 8.9% and 13.3% of cases. It is thus possible to conclude that income gives the household the possibility to access a broader range of energy sources, but even when people start using them, they do not abandon biomass. This phenomenon is known as "fuel stacking".

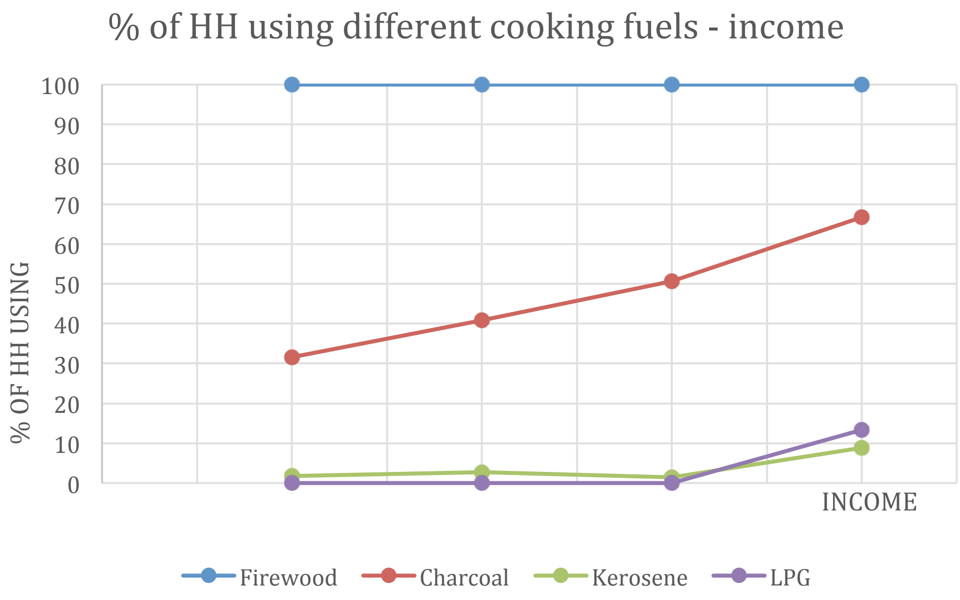

Figure 2.6.1 - Shares of households including different fuels into their energy mix in function of their income [63]

In order to deal with the response of electric energy consumption to income variation, the study by Campbell et al. is considered [64]. In the study, people are divided into four groups of increasing income as well, and the presence of households having electricity in their fuel mix is reported. It is possible to identify two main trends for the percentage of people using current: in bigger towns, with a high share of houses using electricity (90% to 100%), it remains fairly constant with the income variation; in smaller towns with lower current consumption, it grows with the income. It can be expected that electricity consumption grows with the earnings, but this happens only in smaller cities; as reported in this paper, this is because the main reason to start using electricity is the access to grid, and, in order to use electricity to cook, having the necessary appliance. In bigger town almost all household are reported to be grid connected, in smaller once having a higher income allows better houses with power connection and appliances possession. It is even reported that use of fuel wood for cooking is not income related, but wealthier households tend not to use it as primary fuel, and the use of kerosene and electricity does not exclude each other, giving a confirmation of the fuel stacking phenomenon.

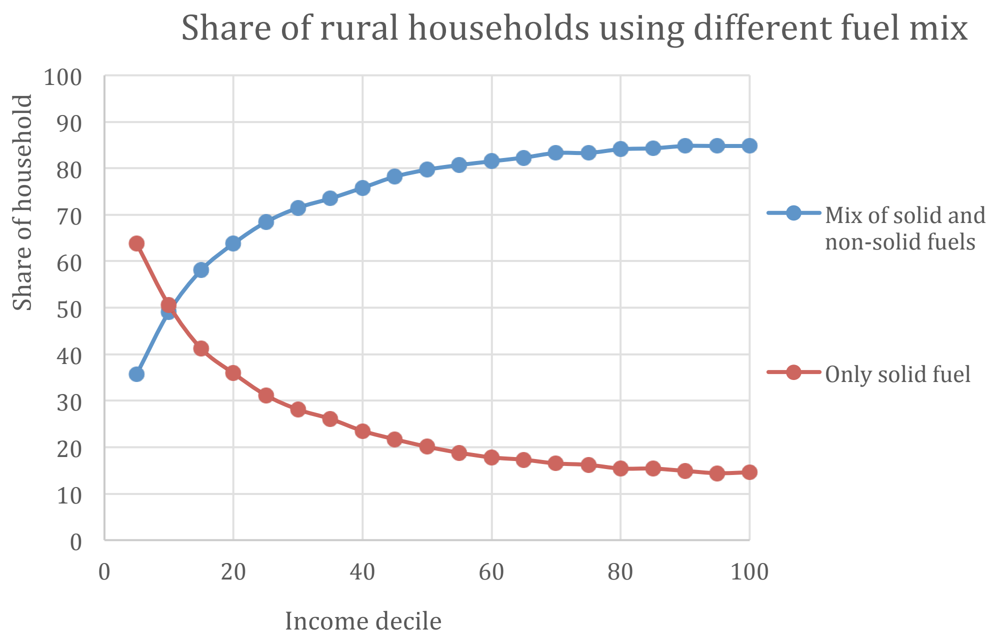

Figure 2.6.2 – Fuel mix in function of income [65]

An interesting representation of fuel switching, from solid fuels only to mixed fuels, is Figure 2.6.2 [65]. In the rural environment the influence of income is really heavy, in fact if between very poor people the share of households using only solid fuels is about 65%, with growth of wealth it decreases plateauing even among the richest around the 20%: this means that always more people start including different fuels like electricity and kerosene into their energy mix, but even among the wealthier households there is solid biomass using, as concluded by Brouwer and Falcão too [21]. In the urban case instead, the main variation is in the richest 10% of the population where some households, up to about 8%, use only non-solid fuels; this very low amount is explained because charcoal is not easily replaced with electricity, and this is because non biomass fuels are not considered adequate to prepare traditional foods. Wambua continues this path in demonstrating that with the improvement of the economic conditions, people continue using biomass to cover their energy needs [62]. It is shown that in Uganda, with the increasing share of population belonging to the middle class and the decreasing of that below the poverty line, happened along the years from 1992 to 2010, the percentage using biomass remains almost constant. And as represented in Figure 2.6.3, the population relying on biomass grows at the same rate that the total population, another proof of fuel stacking.

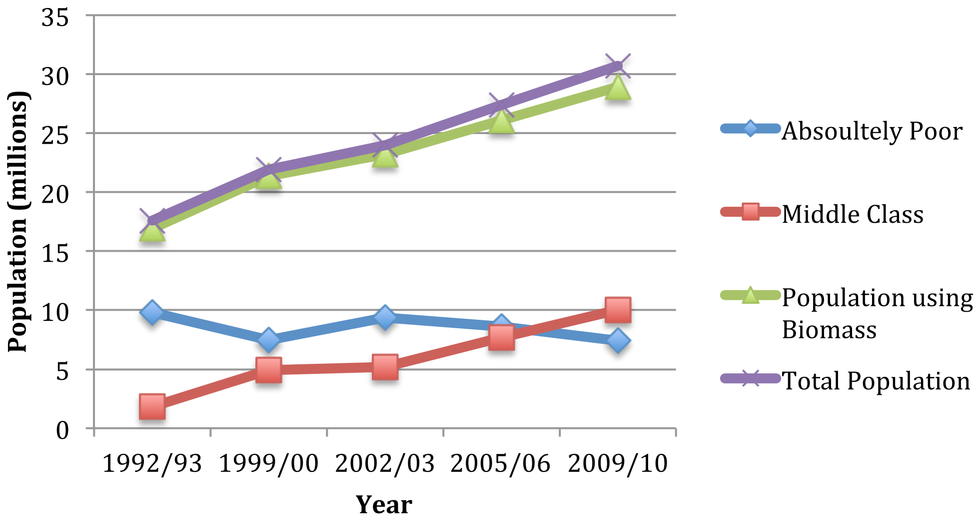

Figure 2.6.3 – Social and biomass trend along the years [62]

Regarding the consumption of charcoal,[62][63][63] in the study "Income Increase Can Still Fail to Influence Fuel Transition" [62] is displayed that the percentage of users increases with the percentage of middle class people, and decreases with the growth of the population below the poverty line. These are proofs that the increase of income can push households to gradually pass from fuel wood to charcoal.

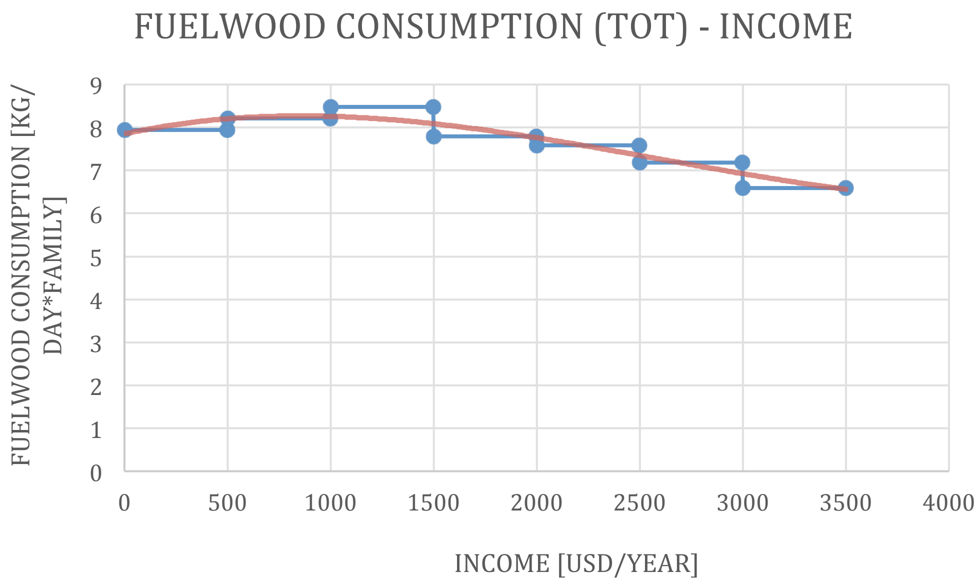

Figure 2.6.4 - Fuelwood consumption in function of income [31]

In Figure 2.6.4, with data from Cambodia [31], there is an interesting inverse U-manner trend in the representation of the amount of fuel wood consumed in function of the income. A first important consideration is that in every strata of the population there is fuel wood consumption. Then the explanation of the pattern is that, for very poor households, having more income implies being able to have a better welfare, and so increasing consumption to cover the not strictly necessary needs; but after that, with the increasing means they start using other energy sources, as seen not necessarily excluding wood, but leading to a decrement in fuel wood consumptions; considering what said above the substitution will probably be with charcoal. It is however to consider that the slope of the curve is always very low.

Interesting data to study peoples' energy behaviour when access to grid is available were found in the work by Madubansi and Shackleton [66], where data are given about the percentage of households using a certain fuel in 1991 and in 2002 in South Africa. It is known that in 1991 almost no one had access to electricity, while after eleven years almost all households in the considered south African villages have had this possibility. In Figure 2.6.5 these data are represented.

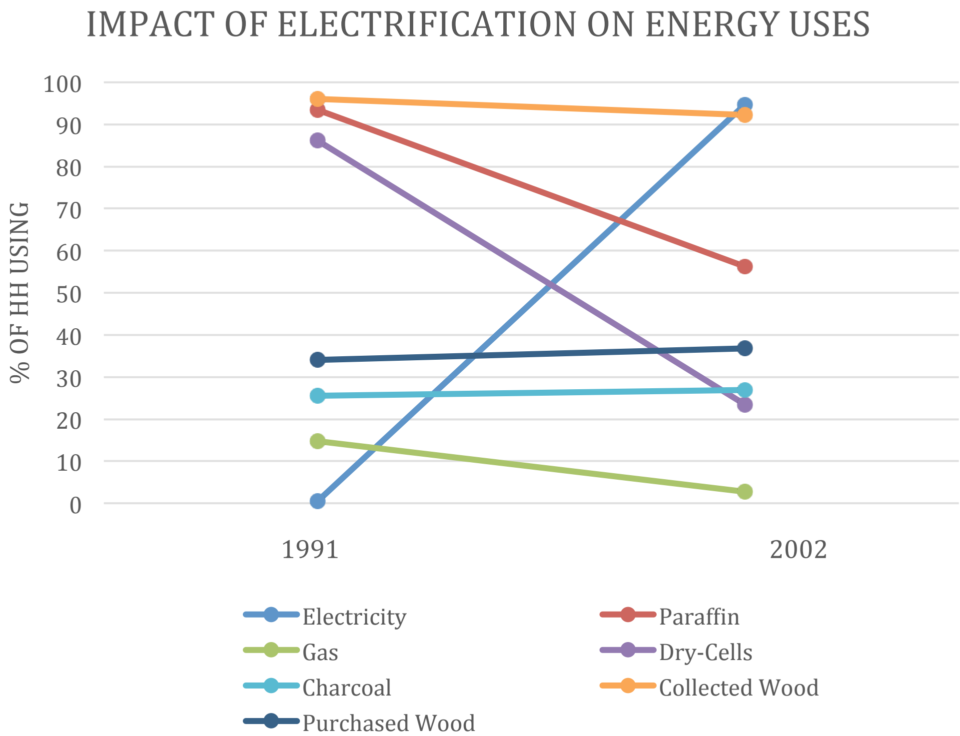

Figure 2.6.5 - Shares of households including different fuels into their energy mix in 1991 and 2002 [66]

It is possible to notice that the shares of families collecting and purchasing wood remain almost constant, and the slight decrease in the former and growth of the latter could be related with an increased difficulty of access to this resource. Charcoal use remains constant as well, while wide differences are found in all other energy sources, in fact the number of paraffin, dry-cells and gas users dropped, and electricity users rise from 0.5% to 94.8%. The explanation of these patterns comes from the fact that electricity has substituted sources for lighting and powering entertainment appliances, such as TVs, radios, mobile phones, refrigerators, but it did not replace wood and charcoal in the energy intense tasks, like space and water heating and cooking. So even in 2002, in a scenario with a deep electrification, even if almost all users have incorporated electricity into their energy mix, it is used together with traditional biomass fuels, which are not abandoned. This can be explicated as found in literature, with several concurring factors, like the high cost of appliances needed to adopt current for heating or cooking, the scarce reliability of the electric service, the cost of electricity itself and the much lower cost of wood (that can be in most cases collected for free) and charcoal, the social and cultural habits that push people not to consider fuels other than the traditional ones suitable to cook traditional foods [16], [62], [66].

An interesting study was found in literature, where it is described how villagers in South Africa react to fuel wood scarcity when electricity is available [16]. The authors consider the cost necessary to fulfil the energy needs, that in case of collected fuel wood is an opportunity cost that considers the time invested in the gathering process, and it results that, even in a fuel wood scarce environment, householders prefer to pay a higher opportunity cost rather then converting to electricity use. The reason of this response is that in this context of rural developing countries, people have much time to invest in fuel wood collection, and this allows them to save on the scarce resource witch is money, with the possibility to invest them in other activities.

	Own price elasticities	**Income elasticity**
Firewood	-0.41	0.45
Charcoal	-0.28	0.32
Candles	-0.88	0.93
Kerosene	-0.79	0.84
Electricity	-0.60	0.69

Table 2.6.1 - Price and income elasticitities of different energy sources [44]

A further analysis to understand energy behaviours, was conducted in Mozambique [44], where price and income elasticities of the demand of energy for domestic consumptions are determined. It is noticeable in Table 2.6.1, as own price elasticities of cooking sources such as firewood (-0.41) and charcoal (-0.28), are much lower than those of the energy sources for lighting considered, like candles (-0.88), kerosene (-0.79) and electricity (-0.60). The meaning of these values is that in case of prices variations, the consumption of wood and charcoal is not going to have wide variations, unlike candles, kerosene and electricity. Same case for income elasticities, explained because traditional energy sources are consumed at the "energy subsistence limit for poor households: they cannot consume less and live" [44], while the others are consumed as luxury sources, whose use is controlled and replaceable according to the economic possibilities. Cross prices elasticities have very low values, implying that the price of one source does not affect the consumption of another one, and this is related with the "stronger relationship between energy source and asset ownership and accessibility" [44], if consumers have a high preference for a certain source, have ease of access and possess the necessary asset, they will favour that source.

2.6.2 Critical analysis

This section analyses the behaviours of households in terms of energy choice. A traditional scheme to describe this phenomenon is the "energy ladder theory", which assert that with an income increase, people will pass from primitive fuels such as fire wood, agricultural waste and dung, to transitional fuels like charcoal, kerosene or paraffin, to modern fuels as electricity or LPG **Figure 2.6.6.** Moving up the ladder means modern fuels, that are more efficient, clean, versatile, less pollutant and thus better for persons and environment, and electricity can give advantages as possibility of light, communication (internet, phones) and entertainment (TVs). Peoples can move gradually up or down the ladder depending on income variations, or "leap frog" which means a sudden switch from one to another energy carrier [67]. Another possible theory is the "fuel stacking", which means that householders, when start using a new energy source they add it to their energy mix, but do not abandon the previous.

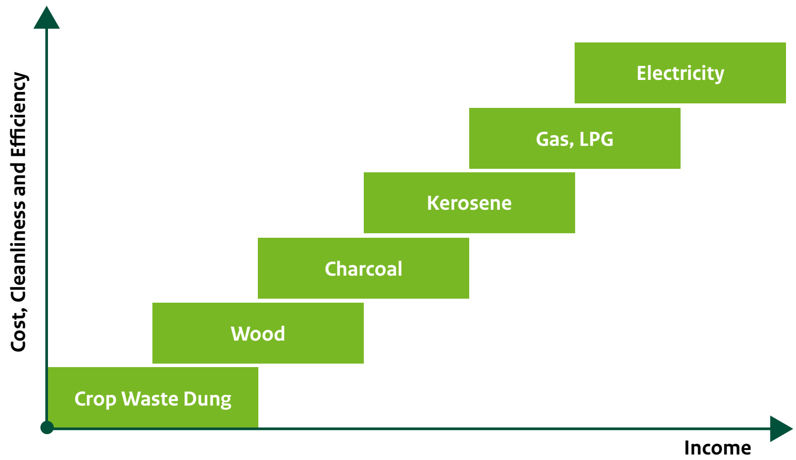

Figure 2.6.6 - The energy ladder [67]

There are many barriers for the upgrading, the first is the availability of modern sources, e.g. access to grid, especially for rural households, which is a necessary but not sufficient condition. Then the economic affordability: both to pay the bill, it is to be considered as well that households can collect fuel wood for free, and to be able to afford the necessary appliance to use a certain source. Another aspect to be considered is the cultural factor: for many locals, modern fuels are not suited to cook traditional foods. The result of these premises is that analysing literature, there is a confirmation that, with an income increase, people include in their energy mix other sources than biomass, but they never abandon it, in fact, more modern sources are used for different tasks, but very rarely for cooking and heating, except for the very higher income strata. As demonstrated by the elasticity values and the very low slope of the U-manner curve, households consume all the necessary biomass they need to fulfil their needs, and the increased income does not eliminate its consumption, but rather some substitution of fuel wood with charcoal. Modern fuels tend to be adopted for task like lighting and communication, that does not require high amount of energy and expensive appliances as could be the case for different types of stoves or heating systems, and in case of income reduction can be easily cut, as noticeable from the high elasticity values. Concluding the energy ladder theory seems not to be validated, and results are more confirming the fuel stacking concept.

While researching for this driver it was possible to find more numeric studies and results than those found for other drivers, but often with measurement of shares of households using some fuel into their energy mix, and rarely with the exact amount consumed. In order to make exact assessments about the energy consumption behaviour, further numeric measurements and studies are recommended.

3 Conclusions

The ultimate aim of this thesis work was to identify and discuss the main drivers influencing use of traditional biomass, conducting a literature analysis and proposing critical conclusions on the basis of considered studies. Considering the great weight of household sector on total energy consumption in Developing Countries, the focus of the analysis concerns biomass demand of families. Comprehension of these dynamics is very important because a careful analysis of factors which lead to a higher consumption of fuelwood is to be considered crucial for future actions aimed at sustainable use of biomass. Hence, International organisation such as the United Nations (UN), World Health Organization (WHO) and the World Bank are engaged in campaigns which objective is to ensure universal access to clean, safe and modern energy services. Unfortunately, the desired result is still far from being achieved and this constitutes a further reason for which a first step research about factors that influence energy choice and consumption behaviour of households is strongly required [68].

From our study it has emerged that the structure of the family and traditions rooted in the mentality of its members are not negligible factors for assessing the biomass demand. In particular, family size results to be an important discriminant for consumption rates in all the considered countries, in which it is clearly visible an inverse relationship between the number of household members and per capita wood use. This reduction in per capita consumption is a result of the presence of economies of scale produced by the presence of a minimum quantity of energy necessary to absolve the main domestic needs such that each additional member increases fuel consumption less than the previous and by the intrinsic inefficiency of semi-open fires that renders more efficient to cook large quantities of food than small because the additional quantities are cooked by heat that otherwise would go to waste.

Households cooking practices have also a great importance. People believe that the best flavour of food is only achievable with traditional methods and for this belief any attempt to induce a switch to different cooking fuels find local's resistance. The same reason constitutes an obstacle in abandoning inefficient habits that are ingrained in traditional cuisine. Some practices have the potential to greatly increase the efficiency of cooking activities but unfortunately only few of them are known by locals and even when are known they are not always practiced, especially where wood is abundant. The diet also influences energy consumptions, because variation of number of warm meals consumed in a day and what is eaten comports variations in fuel needed. As households move from animal product based diet to a maize based diet fuelwood demands increase, in particular whole-grain meals require high consumption of fuel because they need longer time of water boiling. Size of grain flour is also determinant and for this reason meals based on unshelled maize use a double quantity of wood respect to ground maize meals. However, we think that evidences are not enough strong to affirm that wood consumption is determined by cooking practices and diet. Type of meals and how they are cooked surely influence consumption varying the amount of primary energy needed but these aspects remain a secondary variable respect to other drivers that are more important.

The environmental context has also a primary relevance because it influences several behaviours of people from which derive variations in energy demand. Seasonality is a key factor that weight on biomass use, in particular it is appropriate to base every consideration on homogeneous climate-precipitation periods. It emerges that during cold and rainy seasons biomass consumption considerably increases, due to concomitant action of different factors, principally presence of space heating needs, which reach high shares of total energy needs of a household, and the higher levels of moisture in the wood, which cause a decrease in lower heating values of the fuel. It is also important, in order to have a correct estimate of the traditional biomass consumption, to consider: seasonal activities, which become competitive with wood collection in terms of time, seasonal migrations, that cause variations in family size which influence fuelwood rates of consumption, and seasonal fuel prices, which influence household fuel choices and practices. These behaviours are also determined by ease of access to fuelwood resources that are influenced by environmental conditions such as biomass density and deforestation. In particular, as deforestation level increases wood becomes available further and further away implying longer trip for gatherers and higher prices for buyers which cause an initial reduction in fuelwood consumption. Nevertheless, this trend is reversed after a certain distance, in fact when distances become very large the use of fuelwood returns to growth because of household tendency to switch to lower quality wood present in the nearby of their residences.

Finally, the economic and social background results to be very important for household fuel choices and rates of consumption. Rural areas are characterized by a higher firewood use in comparison to urban areas where use of charcoal is significantly greater. While great availability and the possibility to obtain it for free from surrounding areas make wood the dominant fuel in rural areas, in urban centres prevails the suitability of charcoal in small dwelling spaces that makes it preferable despite its higher price. Considering the very low efficiencies of traditional processes for production of charcoal form wood, it emerges that urban families are responsible for a greater per capita consumption of firewood and consequently urbanization appear to be linked to an increasing pressure on biomass resources, especially in surrounding areas of large urban centres. At the same time, even if the urban context provides greater incomes and a greater availability of alternative energy sources, it was found that households do not abandon biomass when they have possibility of using modern alternatives but they merely accompany the latter to fuelwood, which becomes the backbone of a richer energy mix. Generally, these choices are strongly rooted in people mentality and variations in fuelwood prices have very little influence on rates of consumption. Also considering an opportunity cost linked to time lost in wood collection, the situation remains the same: especially in rural areas, households prefer to pay a higher opportunity cost rather then switch to modern alternatives because they have much time to invest and few available moneys. Access to grid has also a little impact, electricity result to be a good substitute for lighting needs but it seems not to be able to replace fuelwood in satisfaction of thermal needs mainly because of high cost of appliances and social cultural habits. In conclusion, "fuel stacking" more than "energy ladder" describes household fuel choices for different levels of income and different social backgrounds.

The main findings are hence summarised:

- Larger household sizes are linked to smaller per capita consumptions of wood, because of presence of economies of scale;
- Type of meals and how they are cooked have potential to influence consumption of wood but they remain secondary aspects;
- Space heating needs and higher levels of moisture in the wood are the main seasonal factors that are responsible of consumptions increase during cold-rainy seasons;
- Increasing distances necessary to reach the biomass resources cause an initial decrease in consumption followed by an increase related to the use of nearest biomass of poor quality;
- Urban households, switching to charcoal, are responsible for a greater per capita consumption of wood resources rather their rural counterparts, so urbanization causes an increasing pressure on biomass resources;
- Greater incomes and availability of energy alternatives enrich household energy mix but they do not depose traditional biomass from its dominant role, mainly linked to fulfilment of thermal needs. "Fuel stacking theory" rather than "Energy ladder theory" describes correctly household energy choice.

Considered these concluding remarks, we have expressed some general conclusions. We believe that probably traditional biomass will continue to have a key role in the energy mix of Developing Countries, especially for its importance in the domestic sector. In addition, the constant population growth in DCs will cause an increase in the consumption of biomass in absolute terms that will submit the environment to more and more important threats. As a result of the inadequacy of "energy ladder model", we think that the actions taken by governments should focus more on promoting methods and technologies that can improve efficiency in the use of biomass rather than on economic incentives aimed at a switch to modern fuels. In this sense, raising local awareness about the problem of unsustainable biomass use is considered crucial, both for a greater propensity to healthier and more efficient behaviours both for initial preparation to the spread of modern and efficient systems. Furthermore, we believe that family woodlots could have a key role in the maintenance of biomass resources, providing the required firewood, and in the control of land degradation, protecting the soil and improving its fertility. Finally, we believe that there is a great need of future quantitative and specific studies about the understanding of the patterns of use of traditional biomass. In particular, one aspect which we think could be an interesting starting point for future research concerns the urban context and the phenomenon of urbanization. In fact, being location of several interesting behaviours, we think that the urban context must be considered with a special attention. In particular, in urban centres families:

- Replace the wood with charcoal, as primary fuel for the satisfaction of their thermal needs;
- Are constituted by a smaller number of members;
- Adopt a diet based mainly on maize meals;

As reported by our thesis, all these factors lead to an increase in wood consumption, so we can affirm that the urbanization is to be considered crucial for the study of the biomass rates of consumption in Developing Countries, where migration from rural areas to cities constitutes an important phenomenon.

In conclusion, we have to remember that a number of different key factors exist and the cause-effect linkage between them is not always clear. It is often not easy to understand how one factor is decisive for a certain result because different drivers could act simultaneously by means of interactions that are difficult to be detected and because they could act differently depending on the local context. Other issues regard low availability of updated data, high variability in the calculation and estimation methodologies and prevalence of data from local surveys. Consequently, there is a strong need of more wide analysis and estimations in order to build further databases based on coherent hypotheses and to scale up from local to country perspective.

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