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CHARCOAL AND FIREWOOD USE IN URBAN AREAS OF DEVELOPING COUNTRIES: DRIVERS, CONSEQUENCES, AND THE NEED FOR CLEAN COOKING SOLUTIONS

Balume, B.S[1,2,3]; Bijnens, L[4]; Abrams, S[4,5;] Banza, B.B[3]; Deferme, W[1,2];

[1]Institute for Materials Research, Hasselt University, Martelarenlaan 42, 3500 Hasselt, Belgium

[2] Division IMOMEC, IMEC, Wetenschapspark 1, 3590 Diepenbeek

[3]High School of Industrials Engineers, Department of Electrical Engineering, University of Lubumbashi, D.R. Congo

[4]Data Science Institute, Interuniversity Institute for Biostatistics and statistical Bioinformatics, Hasselt University, Belgium

[5]Global Health Institute, Department of Family Medicine and Population Health, University of Antwerp, Belgium

ABSTRACT

This study examines the key drivers behind the continued reliance on traditional biomass fuels such as charcoal and firewood in urban areas of developing countries, including the city of Lubumbashi. The paper focuses on economic constraints, health problems associated with the use of these fuels, the environmental consequences of growing use and also looks at the alternatives for cooking and their accessibility.

The various reasons behind the growing and constant use of charcoal and firewood are examined in the context of the city of Lubumbashi and other developing countries. However, the continuous supply of charcoal and firewood not only contributes to the degradation of forests and the extinction of species, but also disrupts the livelihoods of forest-dependent families and exacerbates soil erosion. The charcoal production process is intrinsically damaging to both the environment and human well-being. Not only does it emit large quantities of CO_2, contributing to atmospheric pollution, but it also presents health risks for both producers and users. The smoke and soot generated during charcoal production expose people to harmful substances, leading to adverse health effects and even premature death, particularly among children. This review also discusses the impact of this production and use on the education of women and children, who are responsible for cooking and harvesting firewood, resulting in a higher illiteracy rate among women. Faced with the need to take global action to mitigate the impact of climate change, global carbon dioxide emissions must be drastically reduced to meet the Paris Agreement target of zero net emissions by 2050. A practical and sustainable solution is discussed in this review as an alternative to traditional cooking systems namely solar cooking, which offers enormous potential, provided it is accessible, and is an excellent alternative to the heavy reliance on biomass for household energy needs in developing countries.

Keywords: *Solar energy, charcoal, Charcoal-related health risks, alternative solutions, solar cooker.*

1. Introduction

In the space of a year, the earth is flooded with an amount of solar energy 20,000 times greater than humanity's annual energy consumption (Arunachala & Kundapur, 2020). However, this energy is not distributed evenly around the world (Widén & Munkhammar, 2019). The United Nations Environment Programme (UNEP) has defined the green economy as a means of improving human well-being and social equity, while mitigating environmental risks and enhancing ecological services (Kullane et al., 2022). In Central Africa, as in the rest of the sub-Saharan region, wood is the main source of fuel for cooking, used by over 90% of the population (Branch et al., 2022). In urban areas of developing countries, the widespread use of charcoal and fuelwood can be attributed to their wide availability, affordability, and common practice, aggravated by socio-economic factors such as income level, poverty, and limited access to modern energy sources. The adverse environmental impact of charcoal and firewood use, such as deforestation, air pollution and greenhouse gas emissions, are well documented. In the Congolese wood-energy supply basins, the city of Kinshasa recorded a 75% decrease in carbon stocks between 1984 and 2012 (Etude Qualitative Sur Les Causes de La Deforestation et de La Degradation des Forêts En République Démocratique Du Congo, 2012). In addition, between 2000 and 2012 alone, a 50% loss in the volume of wood was reported, linked to several activities observed in the forest, the main ones being the production of charcoal and firewood, and mining activities. In 2010, the deforestation radius around the city of Lubumbashi increased from 35 km in 2000 to 100 km in 2012 (Nghonda et al., 2023, Muteya et al., 2022). Nevertheless, despite variations in dependence on fuelwood, demand for wood is increasing in many developing countries and is expected to continue to be an important energy source for a significant proportion of the world population. The use of wood energy is increasing steadily, with an annual growth rate of 1.9% (Sepp et al., 2014). By 2030, an estimated 2.7 billion people will rely on wood energy for their needs, as indicated in the 2014 IRENA report (Irena, 2015). This trend can be attributed to the escalating costs of conventional energy sources, which are prompting a greater proportion of the population to turn to other energy sources such as wood energy (Bamwesigye et al., 2020).

To solve this problem, it is essential to explore alternative solutions such as renewable energies, solar cookers and improved access to electricity, which could potentially significantly reduce dependence on charcoal and firewood in these regions.

In this paper, solar cookers are presented as an alternative because they provide free and inexhaustible energy, are in line with current environmental concerns compared with traditional solutions, and are particularly suitable for rural or isolated areas with no access to electricity or fossil fuels. And finally, because they save time for those who collect firewood and do not require a form of energy that is difficult to access and not clean, in particular they are more advantageous for women who cook in the traditional way.(Padonou et al., 2022). The promotion of alternative options depends heavily on government policies, financial incentives, and public awareness (Iessa et al., 2017). The main objective is to analyse the use of charcoal and firewood within urban area in developing countries. On top of that, identification of factors that contribute to the use of charcoal and firewood, and an investigation of the viability of solar cookers as a potential alternative way of cooking, thereby reducing dependence on traditional energy sources, are of key interest. More specifically, an in-depth literature review will be undertaken to gather and synthesise the available knowledge on alternative energy sources and contribute to their recognition for the transition and choice of solar cookers. In addition, an assessment of the socio-economic ramifications associated with the use of charcoal and fuelwood will be undertaken, with a particular focus on disparities in access to modern energy. This analysis will provide valuable information on the societal and economic dimensions associated with energy in developing countries.

2. Methodology

2.1 Researches questions

The research focuses on the following questions: What are the main factors that encourage the use of charcoal and firewood in developing countries,? What are the environmental consequences of the use of charcoal and firewood? What alternative solutions are available to reduce the use of charcoal and firewood, and what are their advantages and limitations? What is the socio-economic impact of charcoal and fuelwood use, in terms of poverty, access to modern energy and inequality? What policies and incentives can be put in place to promote the adoption of alternative solutions and reduce the use of charcoal and firewood?

2.2 Research objectives

The review used a systematic approach to synthesize the available data, in line with the objectives set for the review. Initially, the analysis focused on the use of charcoal and firewood in Lubumbashi and an extended approach to developing countries looking specifically at the amount of charcoal produced in rural areas and transported to the city over a specific time. This provided a contextual understanding of charcoal use within the city. Research was then carried out to explore the cultural factors that determine people's preference for edible sources in cooking, as well as the social and cultural influences that have an impact on this practice. A review was included of the various issues surrounding the use of charcoal, encompassing the deforestation observed around Lubumbashi and analysis of similar circumstances in other developing countries. In addition, the loss of biodiversity of rare forest species, the adverse health consequences associated with the use of charcoal and the generation of air pollution during its production and consumption were also considered throughout the discussion. In addition, the economic implications of this practice have been carefully examined, given both its potential as a source of income generation and its lack of sustainable financial prospects. The final focus of this paper lies on exploring alternative methods for cooking to reduce the dependence on charcoal.

2.3 Literature review

To carry out this review, the literature search was restricted to articles written in English and French, obtained from three scientific databases: Scopus, Science Direct and Web of Science. To ensure a complete and impartial analysis, the search was carried out using specific keywords: "Use", "of", "Charcoal", "Firewood", "Clean cooking", "energy cooking" and "Developing countries". The scope of the research was limited to scientific articles, official government reports and conference papers published between January 2010 and January 2025. In order to provide a practical application, the study reviewed the existing literature on the current situation in the city of Lubumbashi, DRC and extended these findings to developing countries. The aim was to propose alternative solutions, with a particular focus on solar cookers. A collection of 1223 articles was obtained from the aforementioned three databases: Science Direct (752), Scopus (413) and Web of science (58). In addition, 22 relevant articles were manually extracted from various sources. These articles were then filtered according to their titles, ineligibility by automatic sorting systems specific to each database and according to our preferences, duplicate information and articles, abstracts and keywords relating to the use of charcoal and firewood and to developing countries. A total of 703 articles and 12 reports were retained following this selection process where all the criteria and sorting methods are shown in the diagram in figure 1. To ensure maximum relevance, articles with no direct link to our review article were excluded, giving us a total of 491 articles and 9 reports. Finally, 235 articles were downloaded, providing valuable information on the use of charcoal and fuelwood in urban areas of developing countries. In the end 137 articles and 5 reports were subjected to scrutiny because of their more impartial approach to discussing the use of charcoal and firewood in Lubumbashi and enlarged to urban areas in developing countries, the problems associated with it and the promotion of more sustainable cooking alternatives. Figure 1 shows the flow chart depicting article selection, extraction and consultation in accordance to the PRISMA reporting guidelines (Mateo, 2020) on systematic reviews.

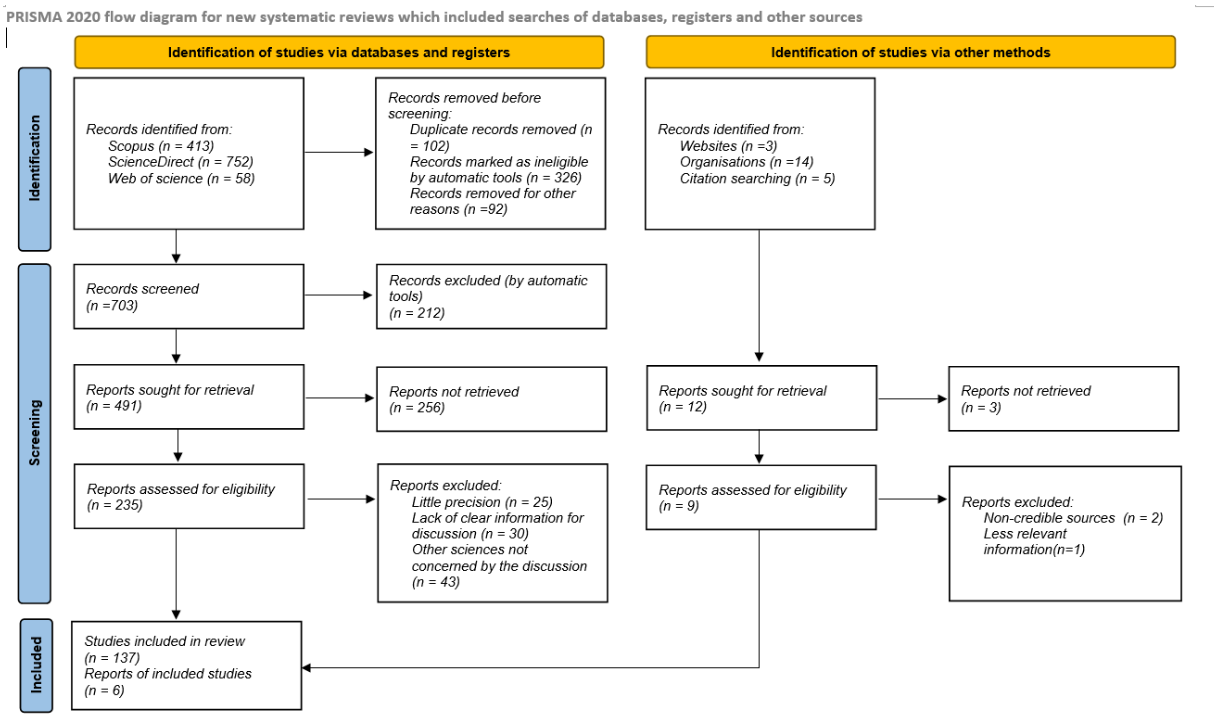

Figure 1: *PRISMA flow diagram illustrating the review process and the selection of eligible articles discussed in this review paper. (Reproduced based from: Page et al., 2021)*

3. Use of charcoal

Table 1 and 2 provide a concise summary of the main findings of this article towards factors related to the use of charcoal and firewood. These publications mainly highlight the widespread use of charcoal extending to developing countries and some examples to the city of Lubumbashi.

In Table 1, several reasons are given to justify this practice.. The level of education, the type of traditional food, the type of dwelling and the ownership of the dwelling are determining factors, as mentioned by several authors. Income level, household size, frequency of meals and access to electricity also play an important role. Professional activity, access to the forest and security issues also influence preferences for charcoal. This analysis provides a better understanding of the complex factors underlying the use of this energy resource in different contexts.

Table 1: *Summary of justifications and preferences for the use of charcoal in different regions. (1) Level of education;(2) type of traditional food;(3) type of dwelling;(4) Household owns the dwelling;(5) income level (economy);(6) household size;(7) meal frequency;(8) electricity access ;(9) Business; (10) access to the forest;(11) security.*

Reference	Location	1	2	3	4	5	6	7	8	9	10	11
Arko et al. (2024)	Ghana					✓			✓			
Brobbey et al. (2019)	Ghana, Tanzanie, Zimbabwe		✓	✓								
Chiteculo et al. (2018)	Angola	✓	✓		✓	✓						
Goyal & Muthusamy (2023)	India	✓	✓			✓		✓			✓	
Hanna et al. (2012)	India		✓	✓	✓	✓						
Herez et al. (2018)	sub-Saharan Africa								✓		✓	
Joshi & Jani (2015)	Developing countries	✓		✓	✓	✓	✓	✓	✓		✓	
Jung & Huxham (2018)	Kenya	✓	✓	✓	✓							
Kissanga et al. (2024)	Angola					✓			✓	✓	✓	
Krämer (2010)	Mali		✓			✓		✓	✓	✓		
Kusakana (2016)	DRC		✓								✓	✓
Lewis & Pattanayak (2012)	Guatemala								✓	✓	✓	
Marandu et al. (2024)	Tanzania		✓			✓		✓		✓	✓	
Mensah et al., (2024)	Ghana					✓			✓	✓	✓	
Mwanasomwe et al. (2022)	DRC									✓		
Nebie et al. (2019)	Burkina Faso					✓	✓	✓				
Otte (2014)	Cameroun	✓	✓	✓	✓							
Ribeiro et al. (2024)	Brazil		✓						✓	✓	✓	

Rosenthal et al. (2018)	Guatemala					✓		✓	✓	✓	✓
Smith & Sagar (2014)	India	✓	✓			✓			✓	✓	
Wentzel & Pouris (2007a)	South Africa		✓					✓			
Zulu & Richardson (2013a)	Ethiopia	✓		✓			✓		✓		
Zulu (2010)	Malawi					✓			✓	✓	

The use of charcoal and firewood raises many concerns (Table 2). Forest degradation and loss of biodiversity are among the biggest problems, with excessive logging often leading to deforestation. Soil erosion is also a worrying consequence. Exposure to smoke and fine particles has major negative impacts on health, particularly for women and children. Inequalities in access to education and energy alternatives make some communities more vulnerable. Negative economic impacts on local populations and inappropriate forest management also contribute to these problems. Excessive dependence on forest resources makes these communities more vulnerable. Finally, the high health risks associated with the use of charcoal and firewood are a major concern. This multifaceted analysis highlights the urgent need to find sustainable solutions.

Table 2: *Summary of problems related to the use of charcoal and firewood (1) Forest degradation;(2) loss of diversity;(3) soil erosion;(4) exposure to smoke and silk;(5) inequality of education;(6) negative economic impacts on local communities;(7) poor forest management;(8) dependence on the forest;(9) high health risks.*

Reference	**Location**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Arko et al., 2024)	Ghana	✓							✓	
Autónoma et al., (2016)	Kenya	✓	✓	✓				✓		
Bailis et al. (2015)	Senegal	✓	✓				✓			✓
Branch et al., (2022)	Africa				✓					✓
Chidumayo & Gumbo, (2013b)	Tropical area					✓	✓	✓		
Chiteculo et al., (2018)	Angola	✓	✓							
Hanna et al., 2012)	India	✓			✓					✓
Idowu et al., (2023)	sub-Saharan Africa				✓	✓				✓

Jeuland & Pattanayak, (2012)	Developing countries	✓		✓					✓	✓
Joshi & Jani (2015)	Developing countries	✓	✓	✓	✓	✓	✓	✓	✓	✓
Jung & Huxham, (2018)	Kenya						✓	✓		
Kissanga et al., 2024)	Angola	✓	✓	✓						
Krämer (2010)	Mali	✓			✓	✓	✓		✓	✓
Kullane et al., (2022)	Somalia				✓					✓
Lewis & Pattanayak (2012)	Cambodia	✓					✓		✓	
Muteya et al., (2022)	DRC	✓	✓					✓	✓	
Muteya et al., (2023)	DRC	✓	✓							
Ngbolua et al., (2018)	DRC		✓					✓	✓	
Nge Okwe Augustin, (2021)	DRC	✓					✓	✓	✓	
Owili et al., (2017)	sub-Saharan Africa				✓					✓
Padonou et al., (2022)	Africa				✓	✓				✓
Péroches et al., (2021)	DRC	✓	✓	✓					✓	
Potential Impacts of Solar Cooking in Afghanistan, (2021)	Afghanistan		✓						✓	
Puzzolo et al. (2016)	Developing countries	✓			✓	✓	✓	✓	✓	✓
Rosenthal et al. (2018)	Guatemala	✓	✓	✓	✓	✓	✓			✓
Schure, (2014)	DRC						✓		✓	
Smith & Sagar (2014)	India						✓	✓	✓	✓
Useni et al., (2021)	DRC	✓						✓	✓	
Zulu & Richardson, (2013b)	sub-Saharan Africa						✓		✓	

3.1 Predominant use of charcoal and firewood: reasons influencing this practice

In most African countries wood comes from wild areas, which encompass a wide range of wooded landscapes such as forests, galleries, savannahs, fallows and fields. With urbanisation and population growth, the supply of wood to meet urban demand has become a major concern in developing countries. This multi-faceted challenge consists of meeting the energy needs of city dwellers, while easing the pressure linked to this activity, which is confronted by several logistical, security and human constraints. Zulu (2010) indicated that fuelwood source areas ranged from 10 to 20 km in the 1980s to 20-70 km in the 1990s, and up to 150 km today around the town of Lilongwe in Malawi (reasons (5), (8) and (9) in Table 1) (Zulu ,2010). The median range of the supply basin is around 25 km for fuelwood and charcoal around the city of Bangui in the Central African Republic (CIRAD, 2019). In Kenya, the charcoal supply chain is heavily influenced by urban demand, particularly in Nairobi, where over 80% of households rely on charcoal for cooking (Autónoma et al., 2016).

In South Asia, in India, fuelwood is mainly used in rural areas, where households rely on local forests for their energy needs. Supply chains here are often informal, involving local collectors who sell directly to households (Bailis et al., 2015). In Bangladesh, although charcoal is used less than firewood, it remains an important source of energy for small industries and urban households (Jeuland & Pattanayak, 2012).

In Latin America, in Haiti, charcoal is the main source of energy for cooking, with a supply chain that extends from rural areas to cities such as Port-au-Prince. This production is often linked to deforestation, posing major environmental challenges (Joshi & Jani, 2015). In Brazil, although charcoal is used less for domestic cooking, it remains an important source of energy for certain industries, such as iron and steel production (Puzzolo et al., 2016). Also, in the DRC, wood is sourced according to the position of each town in relation to the surrounding or neighbouring forests. In Kinshasa, for example, wood comes from villages more than 75 km from the town (Gond et al., n.d.). The city of Lubumbashi is supplied with wood mainly from villages located 100 km from the city, whereas 12 years ago supplies were made from 35 km away only. Some of the firewood also comes from Zambia. The main ecosystem used for wood energy production is the Miombo forest, which dominates the Lubumbashi supply basin (Okwe et al., 2021). Various studies were carried out in other African countries which have shown that the reasons for these activities are diverse and subject to debate, varying from region to region and from culture to culture.

The results presented in the Table 1 highlight the association between increasing use of wood and the socio-economic status of the population on the one hand and accessibility of alternative fuels on the other hand. It is clear that regions with lower purchasing power have a higher proportion of individuals using solid fuels, including firewood, for cooking. In East African countries, where household incomes have risen, some meals are still prepared with charcoal, and the work of cleaning and washing is still carried out using charcoal (reasons (1) and (2) in table 1) (Brobbey,2019). Wentzel & Pouris (2007b) showed that despite the high rate of access to electricity, cultural preferences favour the use of charcoal in South Africa (reasons (2) and (7) in Table 1). Although other studies indicate that households on limited incomes are more likely to use firewood as a cooking fuel because of the financial constraints associated with cleaner fuels, the DRC has an additional reason for certain areas that are plagued by insecurity or that are close to forests (reasons (2), (10) and (11) in Table 1) (Kusakana, 2016). In Lubumbashi, the charcoal production in addition to its domestic use, serves as a source of income for several individuals, making it an activity that involves a variety of functions (reason (9) in table 1) (Mwanasomwe et al., 2022). Socio-economic factors therefore have a considerable influence on the choice of cooking fuel in the DRC, and in Lubumbashi in particular.

3.2 Problems related to the use of charcoal and firewood

3.2.1 Environmental degradation through deforestation and implied loss of biodiversity

On a global scale, environmental degradation is a major source of concern, particularly when it comes to the pressing issues of deforestation and biodiversity loss (Chiteculo et al., 2018). These events have detrimental effects on ecosystems, as well as on the wildlife and human communities that depend on these invaluable natural resources. The process of deforestation involves the rapid destruction of forests by cutting or burning, exceeding their capacity to recover (Alfaro & Jones, 2018). This is often driven by the need for timber, fuel, agricultural space, to name a few (reasons (1), (7) and (8) in Table 2) (Useni et al., 2021).

The DRC has around 125 million hectares of forest, adding up to about 67.9% of the total surface area of the country (reasons (1) and (2) in Table 2 (Muteya et al., 2023). The biomass fuels used are mainly firewood and charcoal, which are renewable resources provided they are properly managed (Okwe et al., 2021). These fuels provide most of the energy used by households, particularly for cooking, in both urban and rural areas, but the stoves used are inefficient and expensive, and have a negative impact on the environment (Péroches et al., 2021).

Biomass is the main source of energy, providing 93.6% of the country's overall energy supply. Oil, hydroelectricity and coal contribute 2.9%, 2.4% and 1.3% respectively of total energy production (Kusakana, 2016). Unfortunately, the use of these fuels leads to the depletion of the country's forests and forest resources, while producing major pollutants that are detrimental for the well-being of those who depend on them. The main source of firewood for the city of Lubumbashi is the province of Haut-Katanga, specifically two territories (Kipushi and Kasenga) and four sectors or chiefdoms (Kisamamba, Kafira, Kaponda and Bukanda) (reasons (1), (2), (3) and (8) in Table 2) (Péroches et al., 2021). However, the Miombo evergreen forest is characterised by a reduction, over time, of its largest area and the complexity of its landscape. As a result, under the impact of human activities, the dynamics of the landscape are mainly characterised by the attrition of the Miombo forest and the creation of wooded areas and wooded savannahs, grasslands, agriculture, and built-up and bare land. The study of Muteya et al. (2023) (reasons (1), (2), (7) and (8) in Table 2) clearly show that Miombo woodland has declined over time, while grassland and wooded savannah have increased their presence in the landscape. The loss of Miombo forest was particularly pronounced in the north-eastern and north-western regions of the Lubumbashi Charcoal Production Basin (LCPB).

In a separate study by Muteya et al. (2023) human impact on the landscape was measured in the vicinity of four settlements in south-eastern Katanga.

(i.e., in Lubumbashi, Likasi, Fungurume and Kolwezi) To assess the applicability of the Nature-Agriculture-Urbanisation model because natural landscapes are replaced by anthropogenic landscapes, first dominated by agricultural production, then by built-up areas. Using a first-order Markov chain, they projected future trends in landscape rehabilitation up to 2090. Using mapping techniques and landscape ecology analysis tools, they found that the natural cover that was once predominant in the landscape in 1979 has declined drastically by more than 60% in area over a 41-year period (1979-2020) around these cities. This decline can be attributed to the expansion of agricultural and energy production, which now dominates the landscape matrix in 2020, as well as to the growth of built-up areas. This increase will occur mainly in the Lubumbashi and Kolwezi regions, leading to a decline in other land covers. However, the Likasi and Fungurume regions will retain a coherent landscape matrix, with a strong presence of agricultural and energy production. Their results highlight the urgent need to explore alternatives to charcoal as a primary energy source.

The decline in biodiversity is a direct consequence of environmental degradation. As natural habitats are destroyed, many species experience increased stress, leading to declining populations and an increased risk of extinction. The consequences of this loss of biodiversity are significant, as the health and diversity of ecosystems are essential to the Earth's stability and resilience. The impact of environmental degradation goes beyond ecological concerns; it also has major socio-economic implications (Jung & Huxham, 2018). The harmful effects of deforestation, for example, directly affect local communities that depend on forest resources for their survival (reason (2), (7) and (8) in Table 2) (Ngbolua et al., 2018). The loss of access to essential forest products, including firewood, wild foods, and medicinal plants, can have a detrimental effect on their general well-being and food security (reasons (2) and (8) in Table 2) (Potential Impacts of Solar Cooking in Afghanistan, 2014)

To preserve the health of our planet and to ensure a sustainable future for future generations, we need to tackle the complex problem of environmental degradation. By actively protecting forests and promoting biodiversity, we can make tangible progress in this effort (Autónoma et al., 2016). It is imperative that we make a collective commitment to preserving natural ecosystems, recognising their vital role in the well-being of our planet and ourselves.

3.2.2 Impact on public health through air pollution and the occurrence of respiratory illnesses

The harmful effects of air pollution and respiratory illnesses on public health stem from a multitude of air pollution sources (reasons (4) and (9) in Table 2) (Branch et al., 2022). The combustion of fossil fuels, industrial pollution, vehicle emissions and various human activities are generally linked to these health problems (reasons (4) and (9) in Table 2) (Kullane et al., 2022). The impact of air pollution, and particularly the presence of fine particles and noxious gases, on respiratory well-being cannot be underestimated. Inhaling these pollutants can lead to respiratory tract irritation, breathing difficulties, lung infections and the development of long-term illnesses. The risk to human health from exposure to charcoal emissions is even greater when the charcoal is burnt indoors (reasons (4) and (9) in Table 2) (Kullane et al., 2022). Figure 2 shows the practical life of the firewood cooking system and the daily exposure of women and children to smoke breathing and burning.

Figure 2: *Firewood consumption by a woman with her child in a developing country (image of world vision France 2023)*

Shockingly, households relying on charcoal as a source of energy faced a 52% mortality risk for children under the age of five in 2014, exceeding the rate of 40% observed in sub-Saharan Africa (reasons (4), (5) and (9) in

Table 2) (Owili et al., 2017). Heavy reliance on biomass for cooking and heating exposes women and children to a range of health risks and environmental challenges:

- The use of traditional stoves and outdated charcoal production processes contributes to indoor air pollution, leading to respiratory and other health problems for women and children;

the inefficient combustion of wood for heating releases harmful pollutants, posing health risks for people exposed to smoke and indoor air pollution (Figure 2).Figure 3 shows the harvesting of firewood by women and children in Africa.

Figure 3: *Harvesting of firewood by African women and children from the forest to their homes(Image from the Congo Research Group and Human Rights Watch report on activities around areas in humanitarian crisis in 2019)*

The production and use of charcoal have been linked to specific adverse health effects (Idowu et al., 2023). The diagram in Figure 4 illustrates the percentage of risk cases of charcoal-related diseases among a group of charcoal producers and users according to a study carried out on the population of several countries in the world

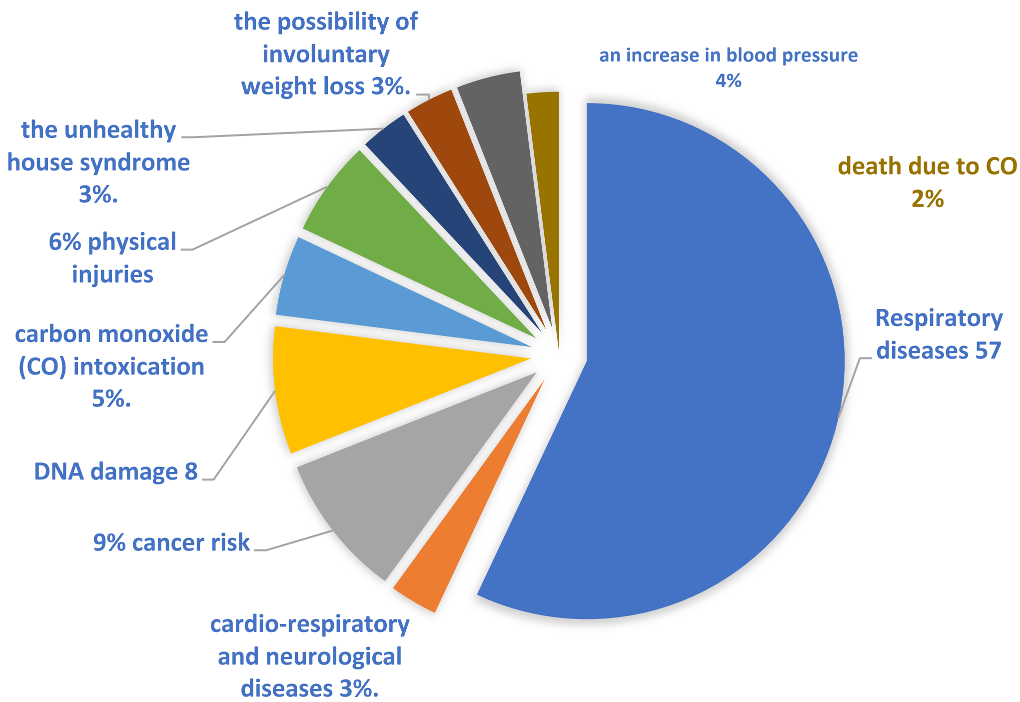

Figure 4*: Percentage of cases of charcoal-related illnesses in the Idowu study of a group of charcoal producers and users* (reproduced based on the findings of Idowu et al., (2023)*.*

To address these public health concerns, it is essential to take action at both individual and political levels. At an individual level, people can play a role by minimising their exposure to air pollution, hence, by using clean fuels and environmentally friendly cooking systems in their homes. Implementing strict regulations on industrial emissions and air quality standards is crucial at a political level. It is also worth investing in cleaner, renewable energy sources (Kullane et al., 2022). In addition, it is essential to raise public awareness regarding health consequences of air pollution and educate the public about preventive measures to minimise individual risks.

3.2.3 Socio-economic consequences for local communities

Although charcoal can be a cost-effective and easily accessible source of energy for cooking and heating, it raises social and economic problems that have a profound socio-economic impact on local communities (Chidumayo & Gumbo, 2013a). Deforestation is a major threat to the local communities that depend on these forests for their livelihoods, as charcoal is an important source of income for rural households in areas with access to urban markets. Figure 5 illustrates the direct effects of the charcoal market in three stages, starting with the harvesting of wood for resale

(Figure 5a), followed by the charcoal production process, which is also responsible for the production of a large quantity of smoke (figure 5b).

Figure 5a *Figure 5b*

Figure 5: *The charcoal production chain from the exploitation of forest trees and its production system Images from the CIRAD 2014 report.*

A study by Zulu & Richardson (2013a) (reasons (6) and (8) in Table 2) examined the socio-economic implications of charcoal production and use, focusing largely on the role of charcoal in poverty reduction based on the four dimensions of poverty defined by the World Bank, i.e.:

- Material deprivation,
- Poor health and education,
- Vulnerability and exposure to risk, and
- Voicelessness and powerlessness.

Poorer households are more likely to participate in charcoal production and sale, but their participation is mainly a safety net to supplement other income. Although charcoal production contributes to poverty reduction through alternative income opportunities, it can also undermine the production of ecosystem services, agricultural production, and human health (reasons (6) and (8) in Table 2) (Schure et al., 2015). The economic study of Nge Okwe Augustin (2021)(reasons (1), (6), (7) and (8) in Table 2) shows the distribution of shares in the charcoal production chain and giving a limited profit of 8% for the production and sale of a bag of charcoal, which must be divided between savings and family survival.

Reducing the dependence of rural households on charcoal requires coordinated policies that provide alternative income opportunities for farmers, affordable alternative energy sources for urban households and more efficient and sustainable approaches to charcoal production and use

(Kusakana, 2016). It should be emphasised that the transition to more environmentally friendly and renewable energy sources can have beneficial socio-economic effects on neighbouring communities. Implementing cleaner cooking methods, such as the use of solar cookers, can reduce dependence on charcoal and save time and money for these communities (Riva et al., 2017).

Supporting local communities in their transition to environmentally friendly energy sources is of the utmost importance. We need to encourage the adoption of sustainable and clean alternatives to reduce dependence on charcoal. By investing in sustainable energy solutions and promoting inclusive economic growth, we can simultaneously improve the well-being of local communities and protect the environment.

3.3 Solutions and prospects for reducing the use of charcoal and firewood

In a study conducted by Schure (2014), it was observed that the majority of people living in Kinshasa and Kisangani, two major cities in the DRC, use charcoal as their main cooking fuel, accounting for over 70% of the population. In Kinshasa, only 12% of households used electricity, while in Kisangani only 1% had access to this energy source. The use of charcoal for cooking has spread throughout the DRC, with 90% of the population relying on it. It is clear that urgent action is needed to solve this pressing problem. Potential solutions to this problem can be linked to several sustainable development objectives, if not all of them.

There are several potential solutions for mitigating the negative effects of charcoal and woody biomass use. Studies carried out in Tanzania (Chidumayo & Gumbo, 2013a), in Uganda (Branch et al., 2022), in Burundi (Riva et al., 2017, Zulu & Richardson, 2013) and Kenya (Jung & Huxham, 2018) proposed the implementation of solar cooking systems that allow food to be cooked in a 100% environmentally friendly way and significantly reduce the use of charcoal.

Studies carried out on the forests of the DRC (Schure,2014, Nghonda et al., 2023, Useni et al., 2022) propose solutions for forest management:

- Strengthen local governance capacities, support private nursery growers in the firewood production sector,
- Disseminate simple technologies to households while reducing biomass consumption,
- Improve the yield of wood carbonisation, to ultimately reduce pressure on forest resources.

Several research studies, including Abdellatif (2019), Noman et al. (2019), Schure et al., 2015, Solar Cookers International (2021), and Vanschoenwinkel et al. (2014), have provided valuable information on the positive effects of solar cookers and renewable energy. These studies have helped to raise awareness and promote education on the adoption of clean and sustainable cooking systems, among other benefits (Chidumayo & Gumbo, 2013b; Mwampamba et al., 2013; Schure et al., 2013):

- Campaigns, demonstrations and promotions aimed at securing future sanitation to save endangered forests;
- Raising community awareness of the health and environmental impacts of biomass use and the benefits of alternative energy sources;
- Develop and enforce regulations: Governments can establish and enforce regulations to ensure sustainable charcoal production, including measures to prevent deforestation, promote reforestation and regulate the charcoal value chain;
- Support alternative livelihoods: NGOs can work with governments to help communities involved in charcoal production find alternative livelihoods, such as sustainable agriculture or agroforestry initiatives;
- Promoting efficient technologies: Governments and NGOs can promote the use of efficient charcoal production technologies, such as improved stoves and cookstoves, to reduce the environmental impact of charcoal production;
- Community engagement: Governments and NGOs can engage with local communities to understand their needs and concerns and

involve them in decision making processes related to charcoal production and sustainable land management;

- Capacity building: NGOs can offer training and capacity building programmes to charcoal producers to improve their practices and promote sustainable production methods.

The results presented in this research paper will provide valuable information to researchers in the fields of energy, environment, and sustainable development. This information will improve our understanding of the use of charcoal and fuelwood in urban areas of developing countries, while exploring potential alternative solutions. In addition, the results will help policy makers formulate effective strategies and initiatives to reduce dependence on charcoal and fuelwood and facilitate the transition to cleaner and more sustainable energy sources. By highlighting the environmental and health impacts associated with the use of charcoal and firewood, the study will raise awareness and propose healthier, more sustainable alternatives. In addition, this article aims to contribute to the political and social discussions currently taking place around the energy transition in developing countries.

4. Alternative solutions

In light of the significant and growing disadvantages associated with the use of charcoal and firewood, there are a number of alternative cooking methods that merit careful consideration. It is crucial to assess these options in the context of developing cities. Table 3 provides a concise overview of the different cooking systems, highlighting their respective advantages and disadvantages. The information presented in this table comes from the perspectives of the articles discussed in this review.

Table 3: Synthesis of a comparative analysis of different cooking alternatives to charcoal cooking

Alternative solutions	Advantages	Inconvenient
Gas cooking	- More practical and less polluting	- purchase cost too high - complex distribution infrastructure - difficult access in rural areas
Electric cooking	- Clean - easy to use	- Depends on the level of access to electricity

		- adequate infrastructure required
Biogas	- Low production costs - Reduced dependence on charcoal	- difficult access - Complex production and application technology
Briquettes from agricultural residues	- Low production costs - Recycling of waste - Easy access to rural areas	- Dependent on farming activities - Complex production and use
Solar cookers	- Clean, free energy - easy to install technology - suitable for rural and urban areas - time and energy saving	- Weather dependent - Need to adapt design to different types of use.

(Synthesis based on the following sources:Cuce & Cuce, 2013; Iessa et al., 2017; Indora & Kandpal, 2018; Rasugu Ayub et al., 2021; Singh et al., 2021; Wright et al., 2020)

The solar cooking system is the most suitable for the conditions and constraints of the city of Lubumbashi, where solar energy is accessible. The possibility of setting up a solar cooker production system to replace the charcoal production system, accessible to all sections of the population and all areas, and the promotion, acceptance and transition to this system will be discussed in the following points.

4.1 Promoting more sustainable cooking alternatives

The promotion of clean cooking energy sources is essential to reduce environmental impact and improve public health. Regulations and policies play a crucial role in this transition. According to Smith & Sagar (2014) incentive policies can stimulate the adoption of clean cooking technologies, such as gas and electric stoves, which are less polluting than charcoal and firewood. In addition, government subsidies for the purchase of environmentally-friendly cooking appliances can reduce economic barriers for low-income households (Pachauri & Rao,2013)

It is also necessary to strengthen distribution infrastructures to ensure access to clean fuels in rural areas. A study by GACC (2019) highlights that improving distribution infrastructure is essential to reach remote populations. At the same time, strict regulations on cooking appliance emissions can encourage manufacturers to develop cleaner technologies (Diederichs et al., 2016).

Promoting sustainable cooking alternatives, such as solar cookers, is crucial to reducing dependence on fossil fuels and firewood, while at the same time offering an environmentally friendly solution that has a positive impact on local communities (Theu & Kimambo, 2023).

Solar cookers harness the sun's energy to heat up and prepare meals (Kanyowa et al., 2021). Using reflectors or solar panels, they capture and concentrate the sun's rays, directing the heat towards a cooking vessel (Vanschoenwinkel et al., 2014). These innovative cookers offer a sustainable and environmentally friendly cooking option, eliminating the need for charcoal, wood, or other non-renewable fuels (Aramesh et al., 2019).

In the DRC, and more specifically in the city of Lubumbashi, there are significant obstacles to obtain modern energy (Bonaventure, 2019) and to adopt sustainable cooking methods. In response to this urgent problem, a collaborative research and development initiative has been launched between the University of Lubumbashi in the DRC and the Hasselt University in Belgium. The main objective of this project is to study the feasibility and long-term viability of solar cookers as an alternative cooking solution for the population of Lubumbashi.

The aim of this effort is to design, build and advocate the use of solar cookers tailored to meet the unique needs of the community. By harnessing the power of the sun, these cookers efficiently heat and prepare meals, eliminating the need for charcoal and minimising harmful greenhouse gas emissions. Our main objective for this project is to improve the standard of living of the residents of Lubumbashi by providing them with an ecological, cost-effective, and sustainable solution for preparing meals. By adopting solar cookers, individuals can minimise the cost of charcoal consumption while preserving the region's precious natural resources. The research and development effort comprises several crucial stages. Firstly, there will be an in-depth examination of the culinary needs and practices of the people of Lubumbashi. The aim of this investigation is to create solar cookers adapted to their unique specifications. Close collaboration between researchers and residents will facilitate a comprehensive understanding of their culinary preferences, financial limitations, and usual cooking methods. The development and production of solar cooker prototypes is being carried out by a dedicated team of researchers and engineers from a variety of disciplines. These prototypes will undergo rigorous testing and optimisation, considering input and suggestions from local users, to ensure that they are efficient, resilient, and user-friendly. Following completion of the solar cookers, a concerted effort will be made to raise awareness and train the people of Lubumbashi in the benefits and proper use of this innovative technology. Through practical demonstrations and educational sessions, residents will have the opportunity to familiarise themselves with the solar cookers and adopt this alternative cooking method. Several research and development results are expected from this project. First and foremost, the people of Lubumbashi will enjoy the benefits of a cooking solution that is not only cleaner and more cost-effective, but also promotes better health. This will mean a reduction in harmful effects on the environment and personal well-being. In addition, the implementation of this project will play a crucial role in building local capacity in the areas of research and technological innovation, particularly in the field of sustainable energy.

4.2 Regulations and policies to promote clean cooking energy sources

Successful wood energy initiatives in developing countries include Abdellatif (2019), Chiteculo et al. (2018), Krawczyk et al. (2018),Brobbey et al. (2019), Alfaro & Jones (2018) and Kamabu et al. (2023). These studies proposed the following solutions:

1. Wood energy policies: Develop and implement policies that support the sustainable development of wood energy, including land tenure and use rights, economic incentives, law enforcement and the creation of a supportive policy and regulatory framework;
2. Mobilising sustainable bioenergy supply chains in agriculture: This initiative, as indicated in the inventory, focuses on promoting sustainable bioenergy supply chains in agriculture, which can contribute to the development of wood energy resources.

These initiatives aim to address the challenges and opportunities associated with the development of wood energy in developing countries, by promoting sustainable practices and contributing to rural development efforts. For more details, please refer to the references provided.

To improve the general well-being of the population and reduce healthcare costs, it is imperative that government bodies launch initiatives focusing on awareness, education, and the implementation of environmental conservation programmes (Gioda et al., 2019). In addition, it is crucial to conduct targeted research in the country to better understand the problem and formulate effective policies (Banza Banza et al., 2020). The ultimate aim of the proposed actions is to mitigate the adverse effects of indoor air pollution resulting from wood burning, thereby improving public health outcomes.

The widespread use of biomass, particularly charcoal, for cooking in developing countries brings with it environmental, health and socio-economic challenges. To address these, policy recommendations need to adopt a broader, more inclusive approach.

- Role of international organizations: Entities such as the UNDP and the World Bank are facilitating the transition to clean cooking solutions by providing expertise, funding and coordination. They set global standards for cooking technologies and foster partnerships to increase their adoption (Smith & Sagar,2014).

Government action: Governments must make clean cooking technologies accessible through subsidies and tax incentives. Investing in infrastructure, such as renewable energy networks, is crucial to the sustainability of initiatives. Prioritizing clean cooking in national policies demonstrates a commitment to public health and environmental sustainability (Jeuland & Pattanayak ,2012; Hanna et al. 2012).

- Awareness campaigns: These are essential for changing behaviour and increasing the adoption of clean cooking technologies. They need to educate about the health risks of traditional methods and the long-term economic benefits. Messages need to be culturally adapted and relayed by local media to reach a wide audience (Puzzolo et al., 2016; Lewis & Pattanayak, 2012).

- Holistic approach: For significant progress to be made, it is crucial to address the interconnected challenges of energy access, environmental sustainability and public health. Collaboration between international organizations, governments and local communities is needed to create an enabling environment for clean cooking solutions (Bailis et al., 2015; Rosenthal et al., 2018).

4.3 Challenges and obstacles to the transition to sustainable alternatives

For the DRC in particular, the energy transition is an opportunity in terms of access to energy, jobs, security, mining, and industrial development using abundant renewable energy resources (Banza Banza et al., 2020). However, several institutional, economic, socio-demographic, and technological factors explain the slowness of this transition (Wentzel & Pouris, 2007b). As the energy transition is a lever for development, it is essential to look at the dynamics of this energy transition, analysing the challenges linked to the energy transition in DRC with the aim of leading the country to take appropriate measures for a sustainable energy transition (Banza Banza et al., 2020)

4.4 Economic costs of solar cookers

The initial costs of solar cookers vary considerably from country to country, depending on the technologies used, materials available, production costs and local policies. Table 4 provides an analysis of initial costs in some developing countries that have adopted this solar cooking system.

Table 4: Prices of solar cookers in different countries around the world

Country	Box cooker prices (USD)	Parabolic cooker prices (USD)	References
India	120 to 130	25 to 650	Joshi & Jani (2015)
South Africa	180.1	300	(Biermann et al., 1999)
Mexico	30 to 60	280 to 346	Herez et al. (2018b)
Nepal	25 to 50	80 to 120	Gurung et al
Lebanon	349		Herez et al. (2018b)

Kenya	40 to 70	150 to 250	Joshi & Jani (2015)
Zambia	120 to 140		Joshi & Jani (2015)
Burkina faso		177.27	Joshi & Jani (2015)
Algeria	75.5 to 100.35		Joshi & Jani (2015)
Tanzania	19 to 748		Joshi & Jani (2015)
Mali	184 to 223		Krämer (2010)
Guatemala	30 to 60	100 to 150	(Rosenthal et al., 2018)
Cambodia	20 to 50	80 to 120	Lewis & Pattanayak (2012)
Senegal	103 to 105.59	100 to 150	Bailis et al. (2015)

From the data in the table above, it is clear that basic models are often more affordable, while high-end models remain a challenge for low-income households. To accelerate the adoption of these technologies, it is essential to put in place subsidy policies, financing programs and awareness-raising campaigns (Mendoza et al., 2019) (Sagade et al., 2023). The studies cited show that solar cookers can play a key role in the transition to clean, sustainable cooking solutions, particularly in developing countries.

Maintenance costs for solar cookers are generally low, but vary according to technology and frequency of use. A study by Arunachala & Kundapur (2020)found that box-type solar cookers require little maintenance, with annual costs estimated at less than USD 5. In contrast, the more complex parabolic models may require more frequent repairs, increasing maintenance costs to around 10-20 USD per year. Furthermore, Jung & Huxham (2018) studied the durability of solar cookers in rural Kenya and found that well-maintained cookers can last over 10 years, reducing long-term costs. However, the lack of spare parts and technical services in remote areas can lead to higher maintenance costs.

One of the main benefits of solar cookers is the reduction in expenditure on traditional fuels such as wood, charcoal or gas (Coccia et al., 2021). In India, Pachauri & Rao (2013) estimated that households using solar cookers save an average of USD 50-100 per year on these fuels, offsetting the initial cost of the cooker in 1-2 years. Similarly, a study by Bailis et al. (2015) in

Senegal found that rural households save around USD 60-80 per year by using solar cookers. However, these savings depend on the availability of sunlight and the frequency of use.

Solar cookers also have significant socio-economic impacts, particularly in terms of public health, reducing deforestation and empowering women (Angappan et al., 2023) (Schindelholz et al., 2024). In Central America, Rosenthal et al. (2018) evaluated the cost-benefit of solar cookers in Guatemala and found that every dollar invested generates socio-economic benefits of $3 to $5, thanks to reduced health and environmental costs. In Southeast Asia, Lewis & Pattanayak (2012) studied the impacts of solar cookers in Cambodia and observed that households using these technologies improve their quality of life, notably through a reduction in respiratory illnesses and an increase in the time available for other economic activities.

4.5 Awareness and acceptance of solar cookers

When assessing the factors influencing the acceptance of solar cookers, it is important to consider, various aspects, including technical, social and cultural variables (Nébié et al., 2022). The evaluation process involves several approaches. Firstly, a thorough needs assessment is required to determine the specific technical requirements and preferences of the intended users (Servín-Campuzano et al., 2022). In addition, it is crucial to assess the compatibility of solar cookers with the daily routines and mealtimes of households and institutions. To understand the adoption of new technologies such as solar cookers, it is important to consider social variables such as user acceptance, preferences, and behaviour. Engaging with the community provides a deeper understanding of social dynamics and potential barriers to adoption (Otte, 2013). Its uptake varies considerably between socio-economic groups, cultural contexts and geographical conditions.

Rural households, often without access to electricity or modern fuels, are potential beneficiaries of solar cooking. However, the adoption of this technology depends on several factors, such as resource availability, cultural habits and level of education. According to Mawhood & Gross, (2014), a lack of awareness and technical training limits the effective use of solar cookers in rural areas of sub-Saharan Africa, highlighting the importance of educational programs to overcome these barriers. In addition, Otte (2013b) found that rural households in India often perceive solar cookers as impractical for meals requiring prolonged cooking, highlighting the need to develop technologies adapted to local needs.

In urban areas, where access to electricity and gas is more common, the adoption of solar cooking is often motivated by environmental and economic concerns. However, spatial constraints and lack of sunlight can limit its use. Paneru et al., (2024) showed that urban households in South Asia are more likely to adopt solar cookers if they perceive long-term economic benefits, such as reduced energy costs. In addition, Pachauri et al. (2025) found that awareness campaigns and government subsidies are key to increasing the acceptance of these technologies in Indian slums.

Women and children often suffer the harmful effects of traditional cooking, such as exposure to smoke and the collection of wood. Solar cooking can improve their quality of life, but its adoption depends on women's empowerment and access to information. Pachauri & Rao (2013) have shown that women in India adopt solar cookers more when they are involved in household energy decisions. In addition, Puzzolo et al. (2016) found a significant reduction in respiratory infections in children using solar cookers, with less exposure to smoke.

Public institutions, such as schools and hospitals, can promote solar cooking by serving as role models for communities. Bhattacharya et al. (2017) showed that educational programmes with practical demonstrations in rural schools in Bangladesh increase the acceptance of solar cooking. In addition, Burton (2014) highlighted the economic and health benefits of solar cookers in field hospitals in East Africa.

Taking cultural variables into account is crucial to understanding the impact of solar cookers. It is important to recognise and respect cultural norms, practices and beliefs that may affect the acceptance and use of solar cookers. By adapting solar cooker projects to align with cultural practices and traditions, we can increase the likelihood of higher adoption rates.

5. Conclusion

The main objective of this research paper was to examine the use of charcoal and firewood in Lubumbashi (DRC), focusing on the wider context of developing countries. The aim was to identify the underlying reasons and factors that contribute to the widespread use of charcoal, and a comprehensive analysis was conducted to understand the various regional and cultural influences that contribute to its prevalence in Lubumbashi. In addition, an assessment was conducted to explore the observed environmental and health consequences associated with this practice, highlighting current and potential future impacts on Lubumbashi if alternative practices are not implemented. The socio-economic consequences of this activity can also be seen in the poverty of the people who depend on the forest for their livelihood. It is imperative to look for sustainable and environmentally friendly alternatives to the use of charcoal and firewood in Lubumbashi. Alternative solutions have been reviewed in this article and after a comparative analysis and in view of the practical and accessible advantages of solar cookers, we believe that this alternative should be considered.

Our research shows that the transition to clean energy faces a number of major obstacles. These include local community resistance to greening initiatives, social and political inequalities, and the absence of comprehensive and sustainable policies and regulations. Furthermore, the association between informality and unsustainability masks the complex and varied social dynamics of charcoal production, and the influence of power dynamics and inequalities on sustainability. In addition, it is essential to invest in education and awareness-raising among the population in order to promote more responsible cooking and heating practices. By adopting these measures, Lubumbashi can move towards a future in which forest resources are preserved, air quality improves and the health of residents is protected. It is time to move towards a more sustainable and responsible use of energy, for the well-being of present and future generations. Given the many disadvantages highlighted in this document regarding the use of charcoal and firewood for cooking, the focus should be on raising public awareness of the extensive use of solar cookers. The "Solar cookers for all" initiative, which focuses on the research and development of solar cookers, holds great promise for addressing the urgent issue of sustainable cooking solutions. With the aim of providing a cost-effective and environmentally-friendly alternative to charcoal, this project strives to improve the well-being of communities while preserving the region's precious natural resources.

To encourage the adoption of clean cooking techniques, future research should focus on the cultural adaptation of solar cookers to community needs, the exploration of hybrid systems combining solar and biogas, the assessment of long-term impacts on health and the environment, and the development of effective awareness-raising strategies. These areas will strengthen the "Solar cookers for all" initiative and support sustainable cooking solutions.

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