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Review

The Role of Energy Efficient Wood Stoves for Reducing Greenhouse Gas Emission, in Ethiopia

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Abstract: Almost 40% of the world's population, or more than 3 billion people, still rely on biomass fuels like coal, charcoal, agricultural residue, dung, and fuel wood for their home energy needs. Over thirty percent of Africa's energy consumption comes from biomass energy. But the majority of Sub-Saharan African nations accounted for 90–98% of household energy use. In Ethiopia, biomass is the primary energy source for almost 95% of households. A review of several published scientific publications was conducted to determine the significance of efficient wood burner technologies in reducing greenhouse gas emissions caused by the burning of wood fuel for domestic energy use. Although the widespread adoption and continuous use of improved cook stoves have the potential to mitigate the greenhouse gas emissions caused by burning biomass fuels for household energy use, the results demonstrated that the combustion of solid fuels for cooking in efficient wood stoves emits greenhouse gases that significantly contribute to climate change. Moreover, it lessens the usage of fuel wood, which lessens deforestation and forest damage. Thus, promoting and maintaining the widespread use of effective wood stoves at the home level can significantly reduce greenhouse gas emissions caused by the burning of fuel wood for energy in the home.

Keywords: Energy Efficient; Wood Stoves; Greenhouse Gas; Emission

1. Introduction

In order to meet their home energy needs, over 3 billion people, or about 40% of the world's population, still rely on biomass fuels like coal, fuel wood, charcoal, agricultural residues, dung, and natural gases[1, 2]. Health, the environment, and socioeconomic development are all negatively impacted when these traditional fuels are used inefficiently in open fires or traditional stoves for home energy usage [3, 4]. Almost four million premature deaths occur each year as a result of the negative impacts of burning biomass, the majority of which are caused by women and children [5, 6, 7].

In most sub-Saharan African nations, biomass energy accounts for 90–98% of household energy consumption, and it accounts for more than 30% of total energy consumed in Africa [8, 9]. According to the references [8–10], four out of every five people rely on conventional solid biomass for cooking, namely fuel wood and charcoal. Two primary energy sources, namely hydropower and biomass, have dominated Ethiopia's energy balance. Ninety percent of all energy demands are met by biomass. Guta [11], states that the nation's forest resources have been degrading as a result of the huge loss of its biomass resources.

Uncontrollably gathering wood results in deforestation, and burning solid biomass fuels for cooking contributes significantly to climate change through pollutant emissions. Several studies have demonstrated that the conventional burning of solid biomass for energy purposes contributes to global warming by emitting greenhouse gases (GHGs) associated with deforestation and forest degradation brought on by the overuse of fuel wood [12]. However, by reducing the need for fuel wood, improved cook stoves and increased fuel efficiency can greatly reduce emissions from cooking and deforestation [13]. Sharing improved cook stove technology is one way to reduce the strain on forests, household fuel wood demand, indoor air pollution, and climate change mitigation [14].

Clean and efficient stoves are estimated to save one to three tons of CO_2e per stove per year using current methods, with 1-2 tons being the most prevalent [15]. Improved cook stoves (ICS) have been shown to provide cleaner, more complete combustion, which can lead to a decrease in greenhouse gas and black carbon emissions. They can also cut fuel use by 30–60% when compared to standard cook stoves [15]. In addition, the utilization of substitute fuels and end-of-use technologies, like effective biomass cook stoves for domestic heating and cooking, can help cut down on emissions [16].

Improved biomass cook stoves can conserve fuel wood by 50% on average when compared to traditional ones, according to Ethiopia's CRGE white Paper. Adding efficient stoves also reduces greenhouse gas emissions in two different ways. By saving about 0.9 t of biomass annually per home, it first lessens the deterioration of forests. Secondly, the potential for sequestering carbon increases with the amount of woody biomass saved from cutting, amounting to 2.1 t per household annually if not burned [17]. As a result, the Ethiopian government has received assistance in its numerous attempts to advance and spread superior biomass cook burner technologies throughout the nation.

Thus, it is crucial to revisit how effective wood stoves are at lowering household fuel wood usage and how they help reduce greenhouse gas emissions. Given that enhanced cook stove technologies are created and distributed throughout Ethiopia in an effort to lessen deforestation and forest degradation, environmental protection, and indoor air pollution mitigation.

1.1. Review Objective

In order to mitigate greenhouse gas emissions caused by burning biomass fuels for household energy, it is important to comprehend the significance of efficient woodstove technologies in reducing fuel wood consumption. Additionally, based on these findings, some conclusions can be drawn.

1.2. Methodology

This review paper aims to gather informative data on the role of energy efficient wood stoves for reducing greenhouse gas emission in Ethiopia. The review was initiated to comprehend current findings about the significance of improved cook stoves for minimizing local and global environmental pollution through reducing the amount of wood fuel consumption, which in turn reduces deforestation and forest degradation, a review of various published scientific types of literature on efficient improved cook stoves and their contribution to greenhouse gas emission mitigation, was conducted.

The data was collected through an extensive and intensive review of relevant literature published from 2000 to January 2024. The primary sources of data for this review were peer-reviewed journal articles obtained from electronic databases such as PubMed, Central, Scopus, and Web of Science. Additionally, other sources like Google, Google Scholar, institutional repositories, annual reports, conferences, gray literature, and books were utilized to access data. I have reviewed 50 published articles to perform this review paper.

2. Literature Review

2.1. The Global Wood Fuel Situation

About 3.9 billion cubic meters of wood are produced worldwide; 2.3 billion of those cubic meters were used as fuel. According to FAO [18], which was reported in Njogu [19], this suggests that over 60% of the wood that is taken worldwide from forests and trees outside of forests is utilized for energy. Wood fuel is approximately 66.6% of the primary energy utilized worldwide roughly 10% is used for heating and cooking in poor nations for different works. According to FAO 2010, which was quoted in Barnes [20] throughout the coming decades, biomass fuels will probably continue to be the principal energy source for millions of rural homes throughout South Asia and Africa.

Since most rural households that burn biomass fuels use inefficient stoves or open fires, it is critical to work toward lowering the demand for wood biomass as an energy source. By doing so, one can reduce the amount of wood consumed, which in turn helps to preserve the environment and the forest resource. **Table 1** below schemes the world's fuel wood and charcoal consumption.

Table 1. FAO projection of wood fuel consumption of the world to 2030.

Wood fuel type		Consumption in million cubic meters						
		1970	1980	1990	2000	2010	2020	2030
World	Fuel wood	1444.7	1572.7	1611.6	1616.2	1591.3	1558.3	1501.6
	Charcoal	21.2	27.0	35.8	45.8	55.8	66.3	75.6

Source: (World Bank, 2011)

As incomplete combustion byproducts like methane and carbon monoxide, which have a greater potential for global warming than carbon dioxide, are released during the traditional method of fuel burning, the overuse of biomass resources for cooking can have an impact on the climate [21]. It is possible to minimize the amount of fuel wood used and emission of black carbon, which relieves pressure on natural resources, significantly lowers smoke emissions, and has also helped to mitigate global warming through the widespread use of ICS [22]. As per Emily [23], Asia and Africa accounted for more than 75% of the production of wood fuel. Global wood fuel output is depicted in Figure 1.

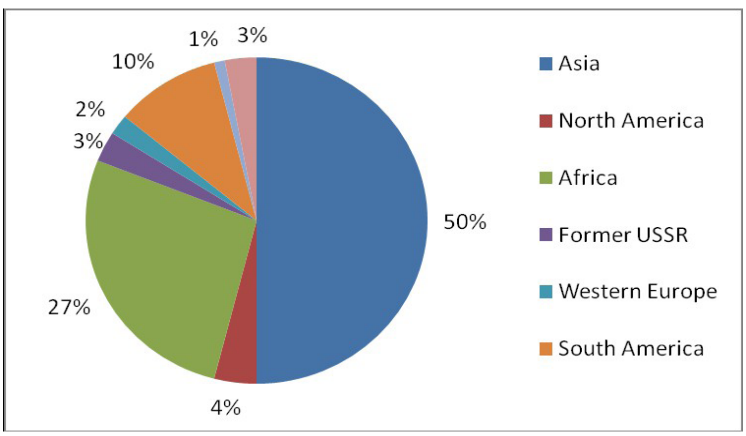

Figure 1. Global wood fuel production (Source: Emily [23].

Thus, it is essential to carefully weigh the increased value of modern cook stoves.

It is evident that the mobilization of Mirt stoves for the aim of mitigating climate change depends on private profits, and more study into time-saving strategies would be very helpful [24]. According to this study, women appear to benefit the most from the Mirt stove, which can save time. But it's crucial to take these findings into account given the typical household labor budget. Can households really save one to five hours a week? If yes, how much does that save them? In order to evaluate the significance of this gain for households, the shadow value of time must also be considered.

2.2. Wood Fuel Situation in Developing Countries

The primary energy source in developing nations is conventional biomass energy, such as wood, charcoal, and animal dung [25]. Over 1 billion tons of carbon dioxide (CO_2) is released into the atmosphere annually from the burning of 730 million tons of biomass annually in developing nations [26]. Improved cook stoves and better fuel could cut down on these emissions. Biomass energy is renewable when production is done sustainably and fuel is used more wisely. In Africa, wood fuel accounts for more than 90% of the wood harvested from forests. A variable but significant portion of the trees that are gathered are turned into charcoal, although the majorities are used directly as fuel wood.

Charcoal is the most significant domestic energy source in many African cities because over 80% of it is used in urban settings [27, 28]. Of the many biomasses, wood is the most significant; nevertheless, reliance on wood differs widely among nations. Wood fuels supply 80% or more of the energy needed in Asia, Kenya, Uganda, Rwanda, and Tanzania in sub-Saharan Africa. Africa will have a higher need for wood fuel by 2030, according to the statistics in **Table 2**, even though there is now a shortage of it. In order to make the use of wood fuel sustainable, it is therefore necessary to use technologies that reduce consumption while simultaneously promoting afforestation.

Table 2. FAO projection of wood fuel consumption up to 2030 in Africa (Million cubic meters).

	Fuel type	1970	1980	1990	2000	2010	2020	2030
Africa	Fuel wood	261.1	305.1	364.6	440.0	485.7	526	544.8
	Charcoal	8.1	11.0	16.1	23.0	30.2	38.4	46.1

Source: Anorld [29]

Approximately 700 million people in Africa are expected to use fuel wood and other biomass fuels between 2000 and 2030, according to estimates from the International Energy Agency [30]. In Asia, the number of consumers is expected to remain at 1.7 billion during this time. If steps aren't taken to adopt better stoves, the impact on greenhouse gas emissions would be severe. This is because better stoves would be more efficient, require less biomass fuel from forests, and help prevent climate change and global warming. In order to meet their energy needs, a considerable number of individuals rely on traditional biomass energy, as seen in **Figure 2**.

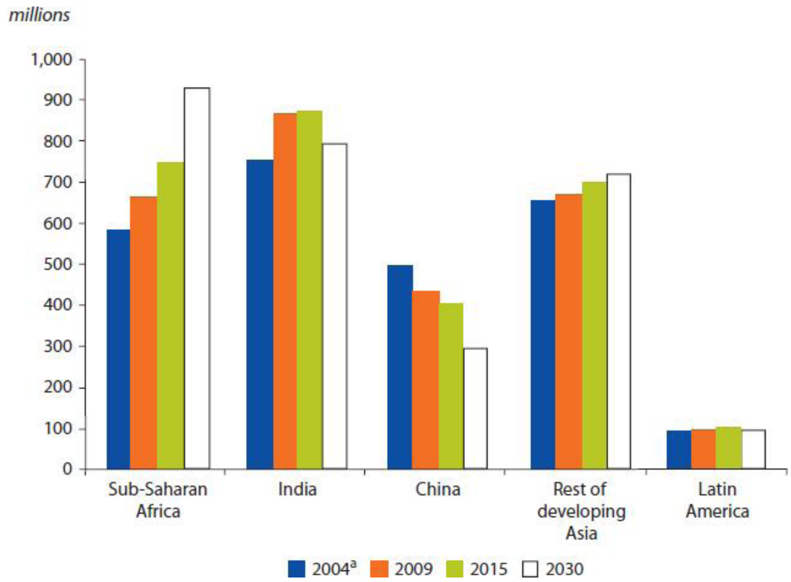

Figure 2. Number of people relying on the traditional use of biomass.

Source: Khatib [31].

2.3. Improved Cook Stove Programs

Better biomass cook stoves were first proposed as a possible means of lessening the negative effects of conventional open-fire cooking. As of right now, they have been around since the 1970s and are primarily "designed for increased fuel efficiency, often because of a perceived link between deforestation and household energy" [32]. Furthermore, better cook stove programs and potential to lessen stoves' impact on climate change have recently focused on the negative health effects of indoor air pollution and safety from traditional solid fuel use [33].

Since then, a number of improved cook stoves (ICS) have been created and promoted in poor nations by donors, non-governmental organizations, and certain corporate sectors [4]. In poor nations where energy is costly and exorbitant, the creation and distribution of ICSs, according to Lnat [34], is a solution for the end user. Since the development and spread of improved cook stoves, over 166 million households in developing countries have relied on them, according to reports from the UNDP [25]. Of these, 116 million are from China, over 13 million are from the rest of East Africa, roughly 22 million are from South Asia, 7 million are from sub-Saharan Africa, and 8 million are from Latin America and the Caribbean [26]. In certain developing nations, the distribution of upgraded cook stoves is depicted in figure 3 below.

Lnat [35] states that the reason for ICS is named a "Mirt" stove is that it was designed specifically to cook traditional food is called Injera, an Ethiopian and Eritrean staple dish that is fermented and eaten on a flat bed. Traditionally, Injera is made using a clay plate called a Mitad, which has a radius of about 60 centimeters and a thickness of up to 4 cm. The natural baking process for injera uses almost no fat; hence the Mitad's low thermal conductivity supports this method. Traditionally, the Mitad is positioned on three stones around an open fire.

Beyene [24] focuses on the Mirt (meaning "best") cook stove, which is used to bake Ethiopian injera, a staple dish. The data shows that the technique saves 22 to 31 percent of fuel per meal, with little to no increase in cooking time, when compared to a normal three-stone stove. According to these data, 88% of Ethiopian forest harvests are unsustainable, which suggests that the Mirt stove—as well as maybe better cook stoves generally can help reduce the harm done to the forests. Under the UN Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation in

Developing Countries, these savings can be eligible for credit.

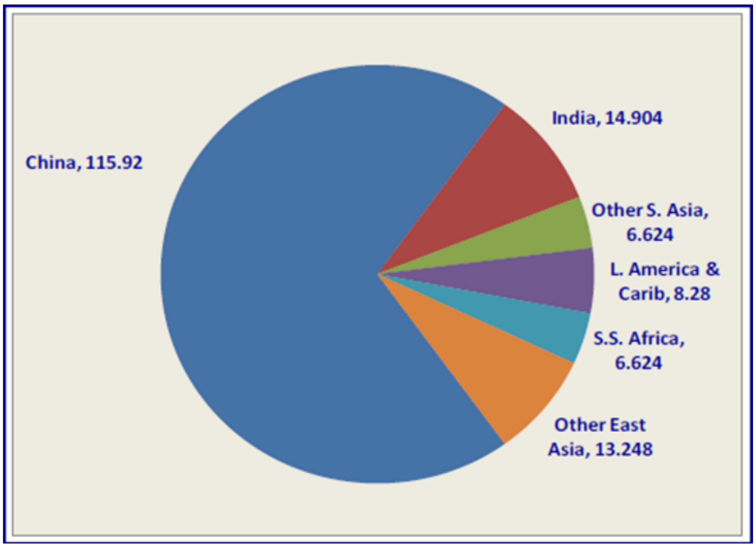

Figure 3. Distribution of improved cook stoves (millions of stoves) Source: World Bank [26].

2.3.1. Major available improved cook stoves in Ethiopia

According to EnDev [36], Ethiopia primarily supports three categories of ICS technology for application in homes and businesses.

The Mirt Stove: is used for simultaneous cooking and injera baking, which is a traditional bread of Ethiopia. With a thermal efficiency of about 22%, it is composed of a sand-cement combination and can save up to 50% of fuel when compared to a three-stone open fire.

The Tikikil Stove: is a transportable cook stove for the home. Made of galvanized sheet metal with a ceramic liner, its thermal efficiency is about 28%, and it can save up to 50% of the fuel used in open fires with three stones.

The Institutional Rocket Stove (IRS): is done with a portable stove called Larger-scale cooking in institutions. The three-stone open fire has a 40–50% thermal efficiency; in contrast, the stove has the ability to save up to 70% of fuel.

2.4. GHG Emission Mitigation Potentials of Efficient Wood Stoves in the World

The saving equal to 11,800 tons of CO_2 saved for 11,156 dispersed ICS, which is equivalent to the amount of carbon stored in more than 30 ha of local forest, when the estimated portion of fuel wood from unsustainable sources is taken into account [35].

The world uses more than half of the wood that is harvested for fuel. Unsustainable harvesting has been linked to deforestation, forest degradation, and climate change due to the depletion of woody biomass supplies. South Asia and East Africa are home to the majority of the unsustainable demand, accounting for some 275 million people who reside in “hot spots” for wood fuel depletion. One to two gigatons of CO_2e are released annually from wood fuel (1.9–2.3%). A reduction of 11–17% might be achieved by the efficient deployment and long-term use of 100 million upgraded stoves. Incorporating black carbon into the carbon market would result in reductions in greenhouse gas emissions of over $1 billion year, based on a price of US$11 per tCO_2e [37].

For many years, efforts to improve home energy have been undertaken with a variety of goals in mind, such as poverty reduction, economic growth, health enhancements, and forest conservation. Assume optimistically that 100 million upgraded cook stoves are effectively distributed; depending on the scenario, this might result in an annual emission decrease of 98–161 Mt CO_2e. By aiming for the highest per capita usage of wood fuel, the most reduction is achieved [37]. According to recent studies, traditional wood fuel generates between 20 and 30 percent of world black carbon (BC) aerosols and around 2% of global greenhouse gas emissions through unsustainable harvesting and incomplete combustion [37].

There is over 730 million tons of biomass burned annually in developing nations. An estimated 1 billion tons or more of carbon dioxide (CO_2) are released into space. The issue is further compounded by additional byproducts of incomplete combustion and climate influences. Improvements in fuel quality and more energy-efficient cookstoves could lower these emissions [26].

Results from Bailis [38] shown that cumulative emissions were lowered from roughly 33 to 66 percent by switching from unsustainable to sustainable firewood collecting and charcoal manufacture. Though it is still just 5–10% of the total emissions of sub-Saharan Africa, it is much lower than the 7–17% in the unsustainable scenario. As per Pine [39], a study carried out in rural Mexico, households that primarily depend on biomass for their energy needs can experience a noteworthy decrease in indoor air pollution and greenhouse gas emissions by implementing upgraded biomass stoves. This can have positive effects on your health.

As per Johnson [33], an enhanced stove has the potential to save up to 10 tons of carbon dioxide annually per home. This would help to lessen climate change and global warming by lowering the amount of greenhouse gases released into the atmosphere.

There are both immediate and long-term effects from better cook stoves in China. In the near term, ICS lowers the emissions of pollutants that pose a health risk, and over time, these stoves significantly contribute to the reduction of greenhouse gas emissions and the mitigation of global warming [40]. Another study carried out in rural northern India revealed that emissions from burning solid fuel in traditional stoves have an influence on household health, the local environment, and global climate change [41] .

An additional study conducted in Senegal suggests that after utilizing improved cook stove technology, users may see a 25–30% decrease in fuel wood usage [42]. Likewise, an investigation conducted in Senegal by Kassi [43] affirms that enhanced clay stoves utilized notably less fuel wood in comparison to the conventional three-stone cook stoves. Bensch [44] discovered in a study done in Senegal that the improved cook stoves use between 39% and 46% less firewood for all meals and dish kinds than the original metal stove, and especially less than the open fire. Based on the meals each home prepares each day, Manoa [45] found that the 1000 local recipients of efficient wood stoves saved a total of 357,700 kg of CO_2 (from outdoor cooking) to 102,200 kg of CO_2 (from indoor cooking) per year in carbon emission reductions.

2.5. GHG Emission Mitigation Potential of Improved Wood Stoves in Ethiopia

The biomass energy sources, including fuel wood, charcoal, dung, and agricultural leftovers, are extremely important to Ethiopia's energy sector. As per Amare [9] and Kanangire [14], the percentage of biomass energy is approximated to be over 90% of the entire domestic energy consumption. It is worth noting that over 95% of Ethiopia's population relies mostly on biomass energy for heating and cooking. There isn't much of a difference in biomass energy use between rural and urban households, despite urban people having better access to modern energy. Reportedly, 94% of households in urban areas and 99% of households in rural areas use biomass energy [14].

It is estimated by MWE that Ethiopia uses 77% of its yearly biomass energy from fuel wood, 13% from animal dung, 9% from agricultural residue, and 1% from charcoal [11]. According to official strategy documents, the climate resilient green economy [17], Ethiopia has committed to promoting improved cook stoves, which will be used by approximately 20 million households and reduce greenhouse gas emissions by nearly 35 million metric tons of CO_2 equivalent by 2030. This is an especially significant commitment made by Ethiopia. Beyene [46] conducted a study which demonstrates that an updated Mirt stove can save roughly 634 kg of fuel wood or 0.94 tons of carbon dioxide equivalents annually on average.

9.4 million upgraded cook stoves will be distributed by the Ethiopian government by the middle of the next decade, as part of its aggressive promotion of their use. Assuming all improved cook stoves delivered function like the Mirt stove, the CO_2e of 9.4 million improved cook stoves the official distribution objective set by the Ethiopian government would be around 8.8 million tons of CO_2 annually. The annual savings from CO_2 would be around US$123 million if the price per ton of CO_2 used in the May 2015 California auction was $13.93. In a different study, Mirt enhanced cook stove fuel wood savings by almost 40% when compared to traditional three-stone fire, resulting in a total yearly fuel wood savings of 1.28 tons per household in the Kefa region of southern Ethiopia [35]. 11,800 tons of CO_2 are saved for 11,156 widely distributed upgraded cook stoves when the estimated portion of fuel wood from non-sustainable sources is taken into account. This confirms that efficient cooking stoves can considerably aid in the preservation of forests and the avoidance of carbon emissions from forest removal and degradation, if they can effectively replace native cooking customs.

The EPA (2004) describes that states that the enhanced Lakech and Mirt stove is predicted to save around 7,778,800 tons of fuel wood year, which would eliminate the need to clear 137,192.24 hectares of forest if all Ethiopian households roughly 14.44 million households used it as stated in [47]. Damte [48] conducted a second study in Ethiopia and found evidence of a "difference among cook stoves in emission and fuel consumption". Better than traditional metal charcoal burners, the Mirchaye and Lakech upgraded charcoal stoves release less CO, CO_2, and PM2.5 pollutants. Optimizing the supply of fuel wood while, minimizing demand is another benefit of using upgraded cook stoves. In Ethiopia, the private sector has been involved in a great deal of programs aimed at improving cook stoves and commercializing them by distributing them to the local population. Because of this, over 3.7 million better cook stoves have been distributed throughout the nation, preserving roughly 30 million hectares of forest annually [49]. [50, 51] report that the annual fuel savings of stoves labeled as "Mirt," "Gonzie," and "Lakech" are 50 kg, 54–64 kg, and 25 kg, respectively. In addition, the annual amount of forest saved (in hectares) is 14, 15, 18, and 7.8 hectares, in the same sequence for each stove.

Energy efficiency technology advancements are vital in developing nations like Ethiopia, whose energy source is primarily reliant on biomass fuels. Ethiopia's government is working to make more fuel-saving technologies, like ICSs, available in order to lessen the burden on its forests and the negative effects of indoor air pollution [52]. According to Damte [48], Merchaye and Lakech saw SFC reductions of 222 and 164 g d−1, respectively. The cooking time was also decreased by the two ICS. In terms of the adoption status of ICS, 43.7% of the sample families had adopted Merchaye stoves, while 31.3% had used Lakech stoves. In contrast, 25% of the sample consists of non-adopters. The age, sex, wealth, and education level of the head of the household all had an impact on the adoption of ICS. The findings could impact household workload, forest degradation mitigation, and climate change mitigation.

According to Alemayehu [49], the CO_2 conserved by the Gonzie stove (1058–1269 tons annually), the Lakech stove (503 tons annually), and the Mirt stove (980 tons annually) would all be comparable. 195,867 Gonzie stoves and 1,282,161 Mirt stoves were distributed in Ethiopia between 2006 and 2013. Using Mirt and Gonzie stoves, respectively, results in the preservation of 18 million and 3-3.5 million hectares of land annually. According to [49], the Mirt and Gonzie Stoves allowed for the sequestration of 1257 million tons and 207-249 million tons of CO_2 greenhouse emissions annually, respectively, from each stove (**Table 3**).

Based on the study of Sepee, and Tesfahun [53], the beneficiary women were able to use EECS to cut their fuel wood consumption by 29.4 kg per week, which decreased emissions and forest degradation by 2.34 tons of CO_2 equivalent per year per home. In addition, it relieved women of some of their labor-intensive tasks by cutting down on the amount of time they needed to cook (53 minutes per day), gather fuel wood (3.95 hours per week), and make fuel wood excursions (3.42 trips per week). While most women in the research region have long suffered from the inconvenience of using traditional stoves and its associated consequences, the adoption of EECS has generally been shown to increase the wellbeing of women in the area.

Table 3. The benefits obtained per ICS type and numbers disseminated.

Stove type	Number	Wood saved(kg)	Forest preserved (ha/year)	CO_2 stored (Million ton/year)
Mirt stove	1,282,161	64,108	17,950,245	1,256
Gonzye stove	195,867	105,768	2,938,005	207
Lakech stove	51,622	12,905.5	376,840	26
Total	1,529,650	182,781.5	21,265,090	1,489

Source: References [50 -51], survey data as cited on Alemayehu [49]

3. Conclusions

Approximately 50% of the global population and nearly all sub-Saharan African nations still rely primarily on solid biomass as their energy source for cooking and heating, thanks to the development of efficient wood stove technologies. The ecosystem as a whole, natural resources, and human health were all negatively impacted by the use of solid biomass for domestic energy usage in inefficient wood stoves. Gases that contribute significantly to climate change are released when fuel wood is burned in conventional cook stoves for domestic energy needs. Deforestation and forest degradation are also consequences of harvesting wood in an unsustainable manner for electricity consumption. Forests' ability to trap carbon decreases as their resource base is reduced. It is possible to cut down on the amount of fuel wood used for cooking and heating, nevertheless, if improved cook stove technologies are widely adopted and maintained. This leads to a decrease in both deforestation and forest degradation. So, better cook stoves offer both immediate and long-term advantages. The reduction in the quantity of fuel wood burned for domestic purposes has a direct positive influence on climate change mitigation since it lowers greenhouse gas emissions. Improved cook stoves limit the amount of trees that are cut down for fuel wood consumption, which improves and conserves the ability of forest resources to sequester carbon.

4. Recommendation

Households will willing to spend more for improved stoves that cut down on cooking time, smoke, fuel wood usage, and durability, according to the report. Furthermore, it shows that using the experiment's stove can be an affordable way to reduce greenhouse gas emissions. This suggests that initiatives that provide financial incentives to reduce greenhouse gas emissions can encourage more people to use stoves if they are implemented well. It is important for policy makers to recognize that the stoves' lack of availability is the main reason they aren't being updated.

To reduce the risk of respiratory-related illnesses among the beneficiaries, the energy efficient stove needs to be redesigned with a chimney that exhausts smoke from inside the huts. Furthermore, a mortar and soil mixture should be used to secure the energy-efficient stove to the floor. This will guard against damage to the stoves and help keep them intact. By building the stove so that the cooking pots are positioned inside, halfway down the inner casing of the stoves, the quantity of heat lost through the conventional manner can also be reduced.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement

The data used to support the findings of this study was found in related published articles that listed in the References.

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Conflicts of Interest

The authors declare no conflict of interest.

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