Performance assessment of KOMBI, energy-saving biomass stove: a gender friendly technology for rural and semi urban communities

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Abstract. The rural population who can hardly afford kerosene and LPG relies heavily on traditional biomass such as fuelwood, charcoal, and crop residues for cooking. The cooking is generally carried out with open fire/traditional stoves such as three stones fire which is inefficient biomass combustion, draining natural resources and consuming a lot of time and energy. Moreover, incomplete combustion of biomass produces a lot of smoke that emit concentrated fumes containing carbon monoxide and particulate solid matter, as well as methane, non-methane hydrocarbons, and black carbon aerosols. It poses a health risk to women and children spending hours in a poorly ventilated kitchen. Since 2017, BP2LHK Makassar has been developing KOMBI (Kompor Biomasa), a biomass-fueled stove, a gender friendly technology, aimed to develop improved biomass cook-stoves to provide cleaner and efficient cooking energy solutions in rural and peri-urban/semi-urban areas. Made of galvanized plate and iron materials, KOMBI consists of two main parts namely a combustion tube and an air chamber that holds and channels air from a 12 Volt, 0.2 Ampere of 12x12 cm² DC fan. For communities around forest areas that have not been reached by the National Electric Company, the use of KOMBI is synergized with the construction of Micro-hydro power or Solar cell. From the results of direct trials in rural communities, KOMBI showed advantages over traditional cooking stoves in terms of: minimalizing smoke, more efficient combustion, shortening cooking time, and reduce biomass usage significantly. Compared to the traditional stoves, KOMBI saves the use of wood in a ratio of 1:10 and speeds up cooking time by a ratio of 1:3. Aside from the amount of wood used, another advantage of KOMBI is that KOMBI can use small size of wood such as tree branches, dried leaves, cacao fruit skin, charcoal briquettes, and even corn cobs. With the calculation of cooking time in the household is an average of 4 hours/day, the cost of electricity consumption for cooking using KOMBI is equivalent to Rp 475,-/month.

1. Introduction
In the developing world, millions people still rely on biomass and fuel wood [1-4]. However, household percentage using biomass declined steadily from the mid-1970s up to around 2000, number of biomass-cookers decline by more than half [5]. Indonesia has also reduced its numbers of fuel wood user by about half from 2007-2016 [6] (Figure 1). As a result of national program converting kerosene to LPG in 2007,
and overall increases in wealth, the use of LPG as the primary cooking fuel has increased dramatically since 2007 [6, 7].

Based on the data from National Statistic Agency [6], the trend of fuel wood consumption is directly related to LPG (Fig.1); LPG consumption increases, the use of fuel wood decline. The same trend also occurs in various countries [5, 8-10]. However, replacing a cost-free firewood with LPG, a costly fuel, is challenging particularly in remote areas [7, 11]. Many rural households are reluctant to buy LPG even at subsidized prices, because they think that they can collect firewood from their surrounding environment for free [11].

The rural population who difficult to afford LPG due to geographical as well as financial constraints, have no other choices of cooking fuel but solely rely on traditional biomass such as firewood or crop residues for cooking. The problem is that cooking activities are generally carried out with open fire/traditional stoves such as three stones fire which is inefficient biomass combustion, polluting, draining natural resources and consuming a lot of time and energy [4, 9, 12-16]. Half of households in developing countries cook with a traditional cookstove generating impact on carbon dioxide emissions and deforestation [5, 16-18]. Incomplete combustion of biomass produces a lot of smoke that emit concentrated fumes containing carbon monoxide and particulate solid matter, as well as methane, non-methane hydrocarbons, and black carbon aerosols [13-16, 19-21]. It poses a health risk to women and children spending hours in a poorly ventilated kitchen [11, 20, 22]. By converting fuel wood to LPG, net carbon emission can be cut by 60% [5]. Unlike LPG which is pollutant-free for indoor use, emissions from biomass combustion are a major source of household air pollution, and contribute to cause millions of deaths worldwide annually [7, 11, 15, 17, 20]. Indonesia is ranked second among countries in the Asia Pacific in terms of deaths caused by air Pollution in households as a result of combustion from solid fuel, 165,000 premature deaths every year [11].

International development organizations have recently stepped up efforts to promote the use of better cook-stoves in developing countries to reduce the harmful effects of burning biomass for cooking and heating on public health and the environment [23]. To contribute to such effort, since 2017, BP2LHK Makassar (Environment and Forestry Research and Development Institute of Macassar) has been developing KOMBI (Kompor Biomasa), an improved biomass-fueled cookstove, to provide cleaner and efficient cooking energy solutions in rural and semi-urban areas.

There have been many studies on the environmental and health benefits of using improved cookstoves in developing countries. However, research on social and economic benefits, especially those relating to women, has not been done too much [23].
This paper is purposed to depict our preliminary research in exploring the effectiveness and efficiency of KOMBI and its potential for mitigating environmental degradation. The effectiveness was tested by comparing the length of time needed to cook using KOMBI with 3-stones traditional cookstoves (TSTC) and gas (LPG) stoves. Meanwhile, the efficiency was analyzed by comparing fuel consumption of KOMBI with traditional stove/open fire and operational cost between KOMBI and gas stove. This paper consider gender aspects of the energy poverty, and how energy-saving biomass stove can contribute in saving women’s time and moving women and their families living healthy and out of poverty. The paper is structured in the following way: section one introduces the general concept of the research; the second provides a description of the design and component of KOMBI; the third points out the research methods we used; and the fifth explains the result and discussion, while the last section provides conclusion.

2. Material and Methods

2.1. Study area

The study took place in Singgang, Katimbang, and Kayubiranga, the three hamlets of Borongrapoa village, The Kindang District, Bulukumba Regency, Province of South Sulawesi (Figure 2). The three hamlets lies in southern part of Lompobatang foothills, on the edge of forest area in the upper watershed of Bialo River.

Figure 2. Study Area

All villagers are farmers, currently earn a living household income mostly from selling coffee bean. The usage pattern for energy in the three hamlets are similar to that of others rural areas in Indonesia. Firewood provided the bulk of energy for cooking followed by gas/LPG. Even though with increasing income from coffee plants they have enough money to fully adopt LPG for cooking, the biomass continues to be used especially for boiling water and cooking rice to save money, while gas stoves are generally used for cooking side dishes and vegetables.

Hence, when money runs out, the villagers have no choice but to use fuel-wood for cooking employing TSTC in bad ventilated indoor kitchen. Commonly, the firewood is obtained from the fallen trunk and branches of trees, coffee pruning, and cinnamon wood (Figure 4). Cinnamon trees are used for firewood after being stripped of bark.

Since 2015, the three hamlets have been electrified by 3 units of MHP with the total power of 27.5 KW which is used to meet household electricity needs and the development of Productive Use of Energy (PUE).
Figure 3. Women cooking over a TSTC in Singgang

Figure 4. The dominant types of firewood available in research area: coffee pruning (left); cinnamon wood (top right), and trees branches (bottom right).

2.2. KOMBI (Kompor Biomasa): a forced-draft Biomass-fueled cookstove
In this paper, the term 'stove' refers to a device that produces heat from an energy carrier to heat a particular device for specific purpose [21]. The design of biomass cookstoves has progressed for decades toward cleaner and more efficient stoves. However, there are ongoing challenges to develop efficient, high-quality products that also satisfy user preferences and are affordable [13]. High-efficiency biomass cookstove is useful in saving time and fuel, significantly reduce harmful emissions [17], and has social and economic impacts that are very beneficial especially for women who responsible in collection and management of household energy [23].
Made of galvanized plate and iron materials, with a total weight of 7 kg, KOMBI consists of two main parts namely a combustion chamber (3” steel pipe), and an air chamber that holds and channels air flow from a 12 Volt, 0.2 Ampere of 12x12 cm² fan to the combustion chamber. By using the State Electricity Company (PLN) base rate in 2019 of Rp. 1,352,-/KWh, the electricity needs to turn on the fan is Rp. 4.05,-/hour (Rp. 0.067/minute). KOMBI is a Forced-draft/fan stove, in which air is blew into the stove using a fan to enhance turbulence and stimulate cleaner combustion. The fan installed in KOMBI, powered by external electricity source to rotate, blows air at high velocity and low volume into the combustion chamber that combusted fuel, air and flame completely; significantly reduces smoke. In rural areas that have not been electrified by PLN, the fan of KOMBI is powered by electricity generated from Micro-hydro power (MHP) or Solar cell.

To accommodate the need of different levels of heat for different cooking purpose (boiling water, cooking rice, frying; etc), we employ a DC dimmer to adjust the air supply to the fire (Figure 5) Dimmer works by adjusting the fan rotation speed to adjust the air flow speed and volume. Blowing too much air can create temperatures that are too low for ignition and reduce efficiency [13].

2.3. Methods
The focus of this study was to determine firewood consumption and time needed for cooking using KOMBI and to describe their impact on household socioeconomic. Data were collected through a household survey and several field testing to understand how KOMBI performs during use in a kitchen with real cooks to observe its effectiveness and efficiency. The effectiveness was tested by comparing the length of time needed to cook using KOMBI with TSTC and gas (LPG) stoves. Meanwhile, the efficiency was analyzed by comparing firewood consumption of KOMBI with TSTC /open fire and operational cost between KOMBI and gas stove. In general, efficiency is a comparison of the useful output of a system to the inputs. For cookstoves, the input is the fuel that produces heat energy through combustion, which is transferred to food or lost to the surroundings [13].

A simple Water Boiling Test (WBT) was employed to assess the performance of KOMBI (time and fuel needed) and compared it with the performance of the TSTC and gas stove. WBT is a method to measure the quantity of fuel consumed and time required for the simulated cooking [24, 25]. The KOMBI at room temperature and the TSTC with the 2 kg pre-weighted of fire wood with bulk density of 400 kg/m³ on average were used to boil 1.3, and 5 liters of water in a 24 cm diameter and 14 cm height pot. To assess the economic efficiency of KOMBI compared to others cookstove, in addition of the TSTC, we also conducted the WBT on gas stove and analyzed the time needed to boil water. Each WBT were conducted three times to obtain the average firewood consumption and cooking duration of each stove. The tests were conducted indoors in cold star condition with limited wind interference. Based on the pretests, it was found that the uniform size of fuel pieces resulting in better performance of KOMBI.
Hence, for the research purpose, firewood were manually chipped into small uniform pieces (10 cm long) to maximize KOMBI performance (Figure 6).

The parameters observed were firewood consumption and cooking duration. The cooking duration was measured using stopwatch, started from stove fire ignition and stopped when water reaches the boiling point (100°C). The temperatures and elapsed time were recorded continuously. Temperature of water was recorded at every 1 minute interval until water reaches boiling point. The volume of wood consumed (grams) was calculated by weighing the remaining unburned firewood and subtracting it from the total volume of firewood prepared.

![Figure 6. Small pieces of firewood](image)

3. Results and Discussion

3.1. Fuel consumption

Firewood is the primary energy source for cooking in the research area. However, in the last 10 years, villagers also used gas/LPG as an energy source for cooking and used it together with TSTC. In general, the total time demand on a woman to collect firewood and to cook for the household are about 3 hours/3 days and 4.5 hours/day respectively.

Based on survey, the each households consumption of firewood was 6.5 kg on average per day (2.3 m³/year) or 1.3 kg/capita/day (average number of households in the research area was 5 persons/household) when the TSTC was used. Meanwhile, gas/LPG consumption per household was on average 6 kg/month (two cylinders of three-Kg cylinder).

3.2. KOMBI performance

A good cookstove generally meets a number of criteria including: efficient, emitting fewer emissions and safer than traditional stoves or three-stone fires [21]. The thermal efficiency of three-stone fires is stated to be as low as 5 to 20% [26, 27], in means that 80 to 95% of the potential heat is lost to the environment outside the cooking pot. Improved cookstoves can reduce the fuel consumption by half by providing an insulated combustion chamber, enhancing air supply, and other measures [27].

From the three WBTs, it is clearly seen that KOMBI consumed less fuel than traditional stove and faster than traditional stove as well as gas stove. Our simple WBT showed that using KOMBI, water boiling point can be reached within in 2.7 minutes/L on average, and heated with the fuel wood
consumption on average of 77 g/L (Table 1). This is better than 3-stones traditional stoves which require on average 8.9 minute/L consume 235 grams of wood to boil 1 liter of water (32.76%). Meanwhile, it needed on average 4.77 minutes and consumed 12 g/L to boil the same volume of water using gas stove. The result of analysis of fuel consumption/burning rate per minute showed that the use of fuel per minute for KOMBI, TSTC and gas stove are 26 grams, 28 grams and 2.5 grams respectively. This result is slightly different with previous study comparing biomass cookstove performance with traditional stoves conducted by Nandi, Patil [24]. Using a WBT, they found that firewood consumption of improved biomass cookstove in cold start condition was far less than that of traditional stoves, 50 g/L compared to 180 g/L. Meanwhile, the time needed to boil water using an improved biomass cookstove is 7 minutes/liter, faster 1 Minute/L than those of traditional cookstove. From our research it can be said that the use of KOMBI can save the use of firewood more than 67.23 % of the use of firewood in traditional stoves.

| Volume | Fuel Consumption (grams) | Time to reach 100°C (minutes) |
|--------|--------------------------|-------------------------------|
|        | TSTC | KOMBI | GS  | TSTC | KOMBI | GS  |
| 1 litter | 250  | 70    | 10  | 10.03 | 2.65  | 5.42 |
| 3 litter | 630  | 230   | 43  | 19.42 | 9.23  | 14.23|
| 5 litter | 1220 | 420   | 54  | 50.88 | 11.87 | 20.80|
| Average | 235 g/L | 77 g/L | 12 g/L | 8.89 m/L | 2.70 m/L | 4.77 m/L |

Remarks: TS = traditional 3 stones cookstove; GS = Gas/LPG cookstove

Figure 7. Fuel consumption and time duration to reach 100°C of the three stoves

3.3. The potential and prospect of KOMBI: increasing women’s welfare and environment concern

It has long been established that poor people mostly use biomass in polluting household energy consumption practices, and women is affected the most [19, 20]. Women is the dominant energy users in the household [1, 19, 28]. A quarter of rural woman’s time is occupied by energy-related activities [19, 22]. Lack of water and energy push women to work harder in providing food for their family [1, 22]. Playing a major role in household activities [23], women are particularly vulnerable to environmental changes impact on energy [22, 29, 30], including the physical and time effects of drudgery in travelling long distances for firewood [1, 19, 31].

Thus, in addition to health and environmental benefits, fuel-efficient cooking technologies can also have social and economic impacts that are beneficial to women [23]. By converting traditional stove into improved cookstove, the hours spent in collecting firewood and cooking can be used to create better
quality family time, generate income through productive activities, or develop capacity through better education [31].

When women get access to quality energy services, there will be improvements in the quality of life of households by reducing the time and effort in energy related household activities and reducing the health risks associated with current energy practices [1, 22]. The massive negative impact of heavily polluted-cooking environment on women health has been explored widely by various researches [1, 31, 32]. However, research on social and economic benefits, especially those relating to women, has not been done too much [23].

In the three hamlets, women spend approximately 3 hours every three days (± 365 hours/year) collecting firewood and 4.5 hours every day cooking on average when using traditional stoves. This finding is almost similar with the previous study in India. Women spend 374 hours every year for collecting firewood and 4 hours every day for cooking [28]. Other study conducted in Pakistan, showed that the average time spent of women on fuel wood collection was about 3.3 – 6 hours per day [33].

KOMBI was designed to optimize the potential of biomass stock in villages surrounded by forest for food cooking and processing agricultural products such as frying coffee and other agricultural products to increase household income. This biomass is usually collected from gardens, yards, farm-plots, forest and other sources in the surrounding settlements.

The most abundant firewood in research site is coffee pruning waste, followed by cinnamon wood and fallen tree branches from the surroundings forest. These material are free fuels, without negative effect on forest. Based on respondent’s experience in using KOMBI, coffee and cinnamon wood are the two best firewood to be used.

Form one year trial of using KOMBI, respondents tended to show positive acceptance. However in general, users complain the hassle of using KOMBI especially at the start of the ignition. Not similar to LPG stove that can easily be switched on and off, KOMBI, like others biomass-fueled stoves, need an extra effort in initial ignition. To enable ignition, there should be ignition aids like paper, thin slices of dried tree branches or bamboo, loose biomass (e.g., dried grass, leaves), or pine resin.

The important impact of KOMBI from the socio-economic side is the savings in the use of time and money to procure fuel and cook. The total amount of firewood saved due to the use of KOMBI was 4.37 kg/day (1.54 ton/year) and the total save time of women for firewood collection and cooking were 0.67 hours/day and cooking was 3.133 hours/day. We assumed that 67.23 % of the firewood savings were savings in collected firewood and that these savings resulted in a corresponding reduction of firewood collection time. In addition, save time of women also comes from time savings due to faster cooking using KOMBI. In total, by employing KOMBI for cooking, a woman saves about 3.80 hours/day (1,388 hours/year).

If we calculate LPG consumption per minute of use, from the above research it can be seen that the LPG consumption per minute of use to boil water in cold start condition is equal to 2.5 grams/minutes and using the current price of subsidized LPG (three-kg cylinder) of Rp.6.67/ gram, the costs to be spent for cooking using gas stoves is Rp. 16.67/minute. If we compare the price per minute of the use of LPG with the cost per minute of electricity usage in KOMBI, then the use of KOMBI is very significant in reducing costs, from Rp.Rp.16.67/ minute to Rp.0.067/minute.

The total savings that can be obtained by using KOMBI instead of TSTC and gas stove are saving fuelwood as much as 1.54 tons/year and saving direct expenditure (the cost of purchasing gas minus the electricity costs of KOMBI) of Rp. 478,000/year.

4. Conclusion

The use of cost free biomass energy has the potential to reduce energy poverty in remote and isolated communities. Yet, it has been known that poor people mostly use biomass in polluting household energy consumption practices. KOMBI was designed to improve the efficiency of heat transfer of biomass cookstove and reduce harmful emission, thereby saving fuel and reducing health impact.

This study was not intended to prove that KOMBI is the powerful tool and the only contributing factor to improve the welfare of rural communities. Instead, it was intended to show that improving energy
consumption pattern can yield social and economic benefits that have the potential to improve the lives of household members. Our study shows that the use of KOMBI is potential to contribute in solving the related-energy problems in rural community. KOMBI has proven to be able to significantly reduce fuel wood consumption, reduce cooking time, save money for LPG purchases, and create healthier kitchen conditions in rural areas. In addition to these advantageous, it is expected that KOMBI will be welcomed by broader rural communities due to its strong and durable construction and economically affordable prices.

A number of KOMBI have been tested for more than a year by rural families with positive acceptance. Nevertheless, to boost this potential and create successful development we need various follow-up trials and even possible KOMBI's design improvements supported by robust analysis to produce more reliable data and information.

The accuracy of all measurement in this research may be subject to question. Different types and condition of firewood as well as type and characteristic of pot may produce different results. However, by conducting trials in real situation and using firewood commonly used on location, both in terms of type or size and condition of firewood, we strive to produce quality data so that it can be used as information for the development of KOMBI and its use.

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