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Air Pollution Resulting from Biomass Combustion in Mozambique: Origins, Consequences, and Measures for Mitigation

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Abstract: Air pollution caused by biomass burning is a main environmental concern in Mozambique. This paper investigates the effect of biomass combustion on air quality, focusing on the sources of pollution, pollutants released, and health and environmental consequences. The substantial reliance on biomass for cooking, heating, and energy generation causes high levels of air pollution from the combustion of wood, agricultural residues, and charcoal. During biomass burning, particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and hazardous air pollutants (HAPs) are emitted, resulting in health hazards and contributing to climate change. Mozambique can considerably improve air quality, safeguard public health, and contribute to sustainable development by using cleaner cooking technology, supporting sustainable biomass management practices, and raising awareness.

Keywords: Air pollution; Biomass; Sustainable biomass management; Public health; Sustainable development

1. Introduction

In recent years, there has been much focus on the health effects of utilizing biomass fuels in developing countries. Particularly emphasizing the emissions of smoke and gases from biomass burning when other features, such as burns, awkward cooking positions, and possible risks when harvesting wood, have received less attention; the negative consequences of wood smoke have been a source of concern for decades. Smith [1] book on Biofuels, Air Pollution, and Health played a crucial role in collecting knowledge in this field in late 1980, providing a complete reference on biomass smoke and pollution and their health impacts. The relationship between biomass fuel smoke and health impacts remains indirect; partly due to the need to integrate environmental and health elements in research [1]. Researchers have moved their attention from monitoring pollution in ambient air with average concentrations over lengthy periods to measuring individual exposure levels to understand the health implications. This technique considers the amount of pollutants a person receives and is more critical to understanding the health consequences than ambient concentrations. While the interest in real exposure stemmed from concerns for employees in industrial production, the direction of the general populace in underdeveloped nations throughout ordinary life provides distinct issues that necessitate more research. In developing countries, a lack of attention to indoor air pollution is frequently linked to more serious public health concerns such as food scarcity, a lack of safe drinking water, and inadequate sewage treatment. Ignoring air pollution issues in such areas can have severe ramifications since the impacts of seemingly minor illnesses, such as air pollution, can compound pre-existing health problems. Investigating air pollution concerns

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in developing nations is critical since assumptions based purely on data from other populations may need to adequately reflect these places' specific context and vulnerability [2-5].

Figure 1. Representative figures for biomass combustion in Mozambique.

2. Sources of Bio-Mass Related Air Pollution

Biomass combustion contributes significantly to air pollution and is a common energy source in many world countries, including Mozambique [6]. Wood, animal waste, vegetables, and seaweed are popular biomass sources. The conversion of biomass into different kinds of energy, such as ethanol, biodiesel, gas, and solid waste, produces a variety of pollutants such as carbon dioxide, carbon monoxide, volatile organic compounds (VOCs), nitrogen oxides (NO_x), and particulate matter. PAHs are generated during incomplete biomass combustion [7], and it is considered a class of hazardous compounds that contribute to particulate matter and have adverse health effects, particularly on the respiratory system and cancer incidence.

3. Pollutants from Biomass Combustion Air Pollution in Mozambique

3.1. Particular Matter ($PM_{2.5}$)

According to research by Huang et al. [8], the average daily $PM_{2.5}$ concentrations in Beijing, Shanghai, Guangzhou, and Xi'an during severe haze spells in 2013 were significantly high. The readings were recorded at 159 g/m^3, 91 g/m^3, 69 g/m^3, and 345 g/m^3, respectively, much higher than the recommended level by the World Health Organization (WHO). Mozambique, like China, suffers issues with $PM_{2.5}$ air pollution, particularly in metropolitan areas with large population concentrations and industrial activity. While thorough data on $PM_{2.5}$ concentrations in Mozambique are lacking, it is plausible to infer that urban areas such as densely populated cities like Maputo and Beira may have increased $PM_{2.5}$ levels due to traffic emissions, industrial activity, and solid fuel use for cooking and heating. Several techniques might be considered to address the issue of $PM_{2.5}$ air pollution in Mozambique. Encouraging clean and renewable energy sources for cooking and heating can help reduce $PM_{2.5}$ levels indoors and outdoors. Furthermore, urban design that promotes sustainable mobility lowers congestion and emphasises green areas can enhance city air quality. Again, public awareness campaigns and education on the health consequences of $PM_{2.5}$ pollution are critical for gaining public support and involvement in pollution reduction initiatives. Strengthening monitoring networks in Mozambique to measure $PM_{2.5}$ levels in diverse locations is also essential for informed decision-making and successful policy design.

3.2. Carbon Monoxide (CO)

Carbon monoxide (CO) is another damaging pollutant emitted during biomass combustion that contributes to Mozambique's air pollution. CO is a colourless and odourless gas produced by incomplete biomass burning. Domestic cooking, heating habits and biomass burning for small-scale industrial reasons are the nation's principal sources of CO emissions. Exposure to high quantities of CO can have serious health consequences. When

CO molecules are breathed, they attach to haemoglobin in the blood, diminishing its ability to deliver oxygen to body tissues. This shortage of oxygen can cause headaches, dizziness, exhaustion, and even death, especially in places with limited ventilation. In Mozambique, where biomass burning is widespread, particularly in rural areas, there is an urgent need to reduce CO emissions. Promoting cleaner and more efficient cooking technology and excellent ventilation can help minimise CO exposure and the health hazards that come with it.

3.3. Nitrogen Oxide (NOx)

As a severe environmental pollutant, Nitrogen oxides (NO_x) are reactive gases produced when nitrogen is burned at high temperatures[9]. NO_x emissions in Mozambique are caused mainly by biomass burning for cooking and heating [10], industrial activities and vehicle exhaust. NOx significantly contributes to creating ground-level ozone and secondary particulate matter, worsening air pollution and negatively influencing human health [11, 12]. Prolonged NOx exposure is linked to respiratory difficulties, particularly in children and those with respiratory disorders Xu et al. [13] suggested several policy recommendations to reduce NO_x emissions, including a supply-demand perspective. They also offered comprehensive insights for decision-makers to consider when formulating air quality improvement strategies. Furthermore, using cleaner fuels and promoting renewable energy sources can help decrease NOx pollution and its adverse effects on public health.

3.4. Hazardous Air Pollutants (HAPs)

Some types of pollutants are hazardous air pollutants (HAPs), which contain harmful substances like benzene, formaldehyde, and polycyclic aromatic hydrocarbons (PAHs). In Mozambique, these pollutants are released into the atmosphere through biomass burning, leading to air pollution and significant health concerns for the population. Exposure to HAPs can harm human health, including cancer, neurological impairments, and reproductive issues. These harmful contaminants have a more significant impact on vulnerable groups such as children and pregnant women. To mitigate the release of HAPs, Mozambique must adopt measures to limit biomass burning and develop cleaner energy sources. Additionally, strict limits on industrial emissions and the promotion of more sanitary technology can reduce HAP emissions and safeguard public health.

4. Impacts Resulting from Biomass Burning

4.1. Air Quality Impact

Biomass combustion is a major global issue in Mozambique, as in many other parts of the world. This practice emits significant amounts of gaseous and particle pollutants into the atmosphere. These pollutants include carbon dioxide (CO2), carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter with diameters of 10 micrometres or smaller (PM_{10}), fine particulate matter with diameters of 2.5 micrometres or smaller ($PM_{2.5}$), black carbon (BC), organic carbon (OC), elemental carbon (EC), and other compounds. It is critical to highlight the possible threats posed by these emissions and their influence on air quality in Mozambique, where biomass burning is also prominent. Implementing biomass combustion control and reduction methods, particularly in agricultural operations involving crop residue burning, might be critical in protecting the region's public health and the environment. Furthermore, further research and monitoring efforts are required to understand the unique implications of biomass combustion in Mozambique and to establish appropriate methods for the long-term management of biomass burning to limit its adverse effects on the environment.

4.2. Health Effects of Air Pollution

Air pollution from cooking fires in developing countries can have various health effects associated with the compounds present in the smoke. These compounds include gases such as CH_4, CO, NO_2, and SO_2 and liquid or solid compounds, mainly of organic origin, forming a complex mixture known as particulates or PM (particulate matter). Particulates are composed of complex organic molecules, including aldehydes and polyaromatic hydrocarbons (PAHs), with formaldehyde (HCHO) and Benzo-a-Pyrene (BaP) being well-known examples. Acute health consequences of exposure to smoke and gases from cooking fires include eye and throat discomfort, coughing, and headaches. Gases are commonly connected with immediate effects. Long-term exposure to particles, conversely, can result in more severe health implications like wheezing, chronic bronchitis, and even lung and airway malignancies. Chronic carbon monoxide (CO) exposure is also a health problem. While the acute effects of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are well known, their long-term health impacts remain contested. Addressing the health consequences of air pollution from cooking fires and biomass burning is critical for developing nations like Mozambique. Implementing actions to decrease biomass burning and promote clean and efficient cooking technology will help alleviate the negative health impacts and safeguard the region's public health and ecology.

4.3. Climate and Weather Impact

Globally, biomass combustion is integral to global warming, accounting for around one-fifth of CO2 and other greenhouse gas (GHG) emissions. These emissions are related to various biomass combustion activities, including wildfires, slash-and-burn agriculture, and wood trash burning [14, 15]. Carbonaceous aerosols released directly or generated during Biomass combustion are dispersed less evenly than long-lived and well-mixed GHGs, resulting in regional climatic consequences. The radiative forcing due to Biomass combustion particles at the top of the atmosphere was estimated by the Intergovernmental Panel on Climate Change (IPCC) to be close to zero (0.0 0.2 W/m^2). Vertical fluctuations in biomass combustion-induced climatic forcing, on the other hand, are seen. Light-absorbing smoke plumes heat the middle and lower atmosphere by absorbing solar radiation while lowering net radiation at the surface. Furthermore, smoke particles operate as Cloud Condensation Nuclei (CCN), chilling the surface, stabilising the atmosphere, and regulating cloud dynamics and precipitation patterns [16-18].

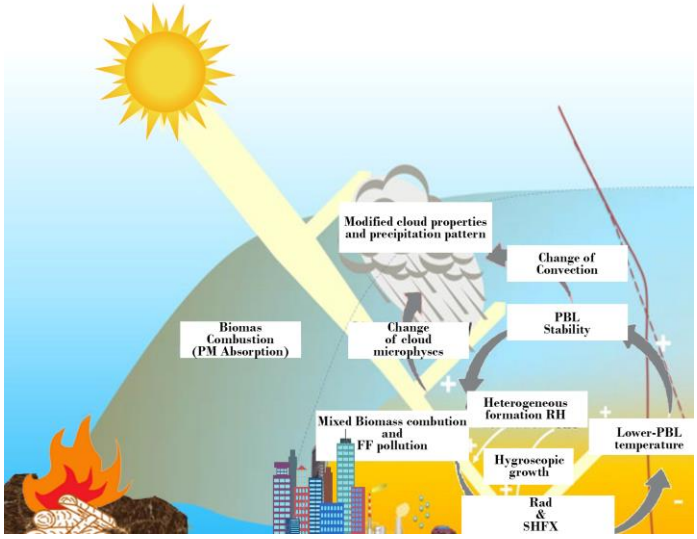

Figure 1 A schematic figure for interactions of air pollution (Modified from Ding et al. [19]).

The influence of Biomass combustion on regional air quality and climate in Mozambique is more complicated because of the overlap of straw-burning sites with fossil fuel

combustion sources. Because of this overlap, mixed pollution situations alter convective precipitation patterns. Using satellite data and modelling simulations, researchers in China's Yangtze River Delta (YRD) have found examples of hybrid biomass combustion and anthropogenic pollution impacting convective precipitation [20]. Under the effect of air pollution, such circumstances might result in higher precipitation levels and increased rainfall rates throughout cloud lifetimes. However, Biomass combustion aerosols may also impact localised convective precipitation during the day, causing changes in surface flux and boundary layer dynamics. In contrast, downstream rainfall can be increased at night due to biomass combustion's indirect impacts on cloud microphysics and circulation alterations produced by dynamic forcing. Biomass.

5. Intervention Strategies and Areas for Future Study

Comprehending the health effects of air pollution in impoverished nations is crucial. The World Health Organization (WHO) has prioritised research on the causal connections between acute respiratory infections (ARI) and biomass combustion emissions. The WHO has also emphasised the need for additional research into the various health impacts of biomass smoke exposure, such as unfavourable reproductive outcomes and chronic obstructive pulmonary disease (COPD). To carry out effective interventions, it is crucial to consider certain local factors, such as differences in the natural environment, climate, energy usage (e.g., for cooking or heating), local infrastructure, user behaviour, and sociocultural conditions. For example, changing housing structures, such as having a separate kitchen or additional windows, can help reduce exposure to pollutants. However, it's essential to recognise that the impact of such changes may be limited for individuals who cook near their fires. Additionally, implementing cleaner fuel-burning methods through pre-processing may be suitable in specific geographic locations, such as charcoal in sub-Saharan Africa or biogas in parts of Asia. These location-specific approaches can contribute to more effective and sustainable solutions for mitigating biomass-burning-related air pollution in Mozambique. McCracken et al. [21] performed research in Guatemala that provided valuable insights into the health implications of solid fuel consumption and the potential advantages of the 'plancha' chimney stove. This stove lowered smoke exposure considerably, as indicated by lower levels of inhaled carbon monoxide, a well-established surrogate measure for indoor air pollution. Furthermore, individuals who used the 'plancha' stove reported fewer symptoms related to indoor air pollution, such as irritated eyes and back discomfort. These preliminary findings have spurred interest in investigating the stove's application in similar countries, including Mozambique. Mozambique, like Guatemala, faces challenges associated with indoor air pollution resulting from the prevalent use of solid fuels. The 'plancha' chimney stove shows promise as a potential solution to mitigate indoor air pollution in Mozambican households. By reducing exposure to harmful smoke and particulate matter, the furnace can improve indoor air quality, thus positively impacting the health of household members, particularly women and children who often spend significant time near cooking areas. However, it is critical to note that data on spirometric measures, birthweight outcomes, Acute Lower Respiratory Infections (ALRI) rates, or other comprehensive health statistics connected to using Mozambique's 'plancha' stove have yet to be published. As a result, before deploying this stove on a broader scale, it is critical to perform more studies to examine its efficacy in the Mozambican environment adequately. Additional randomised controlled trials and longitudinal research are needed to determine the genuine health advantages of Mozambique's 'plancha' chimney stove. These studies should include a broad population that reflects the country's socioeconomic and cultural diversity. Researchers may acquire a thorough picture of the stove's influence on public health in Mozambique by assessing numerous health indicators like as spirometric measures, birthweight outcomes, and ALRI rates. The first randomised controlled trial conducted in Guatemala demonstrated promising results regarding the health effects of solid fuel use and the potential benefits of the 'plancha' chimney stove. While these findings are encouraging, the applicability of this stove in

Mozambique requires careful consideration and further research. Addressing indoor air pollution is a critical public health concern in Mozambique, and the 'plancha' stove could serve as a valuable intervention to improve indoor air quality and alleviate related health issues. Through rigorous investigation and evidence-based decision-making, Mozambique can work towards a sustainable solution to promote healthier living conditions for its population.

6. Conclusion

Biomass burning is a major environmental issue in Mozambique as it causes air pollution that seriously affects human health, ecosystems, and development in the long run. Using biomass fuels like wood, agricultural waste, and charcoal is widespread throughout the country for cooking, heating, and energy production. This research presented an overview of the influence of biomass burning on air quality in Mozambique, concentrating on pollution sources, released contaminants, and the health and environmental consequences. The emissions of particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), and hazardous air pollutants (HAPs) jeopardise human health during biomass burning. Prolonged exposure to these pollutants can cause respiratory and cardiovascular problems, especially in susceptible groups, including children, older people, and those with pre-existing health concerns. Furthermore, biomass combustion contributes to climate change and global warming by emitting greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4). Air pollution from biomass burning has far-reaching repercussions that affect regional and international climate trends. Mozambique's air pollution from biomass combustion needs immediate and comprehensive intervention. Cleaner cooking technologies, such as better cookstoves and biogas systems, are critical for reducing reliance on conventional biomass burning. Raising awareness of the health dangers of biomass combustion and enabling access to alternate energy sources are crucial first steps in addressing this issue. The government, non-governmental groups, and foreign partners must work together to make real progress. Finally, the need to address air pollution caused by biomass combustion in Mozambique cannot be emphasised. All parties must work together to adopt policies that encourage cleaner energy sources, decrease emissions, and safeguard the population's and the environment's well-being. Mozambique can make tremendous progress toward improving its air quality and establishing a better and more sustainable future for its residents by working together toward this shared objective.

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