審査の結果の要旨

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Dissertation Title:　Adoption and impacts of clean bioenergy cooking technologies in rural Kenya: A transect approach in Muranga and Kiambu counties

Access to modern and sustainable cooking energy has moved at the forefront of the international policy discourse and has been enshrined in a dedicated Sustainable Development Goal (SDG7) on energy. Apart from being a key element of SDG7, access to safe and sustainable cooking energy is also central to achieving other SDGs pertaining to poverty alleviation (SDG1), good health (SDG3), gender equality (SDG5), ecosystem conservation (SDG15) and climate action (SDG13), among others.

Like other parts of sub-Saharan Africa, Kenya has been striving to modernize its household energy system. The adoption progress has been notably slow, with only 14% of Kenyans currently having access to clean cooking options such as biogas, liquefied petroleum gas (LPG), solar or ethanol stoves and 26% using improved biomass stoves. This situation seems a bit paradoxical considering that Kenya has a long-established clean cookstove sector compared to other SSA countries. Several researchers have *"requested"* for more nuanced local-specific policies and holistic scientific assessments to fully understand the sustainability challenges of traditional bioenergy cookstoves.

In order to address the inherent knowledge gaps, this research assesses the factors of adoption and the impacts of clean bioenergy cooking interventions in Kenya and propose policies that could enable scaling up their adoption. The specific focus is on the dynamics between traditional and modern (i.e. biogas, improved biomass stoves) cooking options in rural settings of the Murang'a and Kiambu counties. The specific objectives include to: (a) identify the drivers, challenges and perceived impacts of clean cooking interventions in Kenya through expert interviews; (b) elicit user preferences and trade-offs inherent to stove choice behavior using household surveys and choice experiments; (c) identify and asses the impacts of cooking energy technologies through a mixed-method approach; (d) suggest policy and practice options to influence sustainable transition pathways for achieving universal access to clean cooking in Kenya.

First, an extensive literature review was conducted to synthesize the current knowledge about historical development of cooking technologies, policies, stakeholders, impacts and factors of adoption of clean bioenergy cooking interventions in Kenya. For objective (a) 28 semi-structured key expert interviews sought to elicit the perspectives and insights of the main stakeholders involved in the Kenyan stove sector about adoption (drivers and barriers), perceived impacts and requisite

approaches to enable scaling up access to clean cooking in Kenya.

For objectives (b) and (c) household surveys were collected along two biomass transects in the two study districts. In particular, both transects sought to reflect increasing fuelwood scarcity, and traversed from the state forest towards the urban center (Kiambu) and the semi-arid interior (Muranga). Approximately 200 households were selected randomly in each study transect, with a further 100 biogas users purposively selected in the Kiambu transect. For the first part of objective (b), it was hypothesized that stove adoption is predicated on a linear combination of demographic, socioeconomic, institutional and ecological factors. A probit regression model was used to estimate the probability of the hypothesized variables on adoption of biogas and improved biomass stoves. A path analysis was further carried out to determine the direct, indirect and total effects of productive resources on stove adoption. In addition, a qualitative mapping of 23 participatory ethnographic surveys was carried out to identify contextual factors affecting stove acquisition and sustained use. For the second part of objective (b), a stated preference survey and discrete choice experiment was designed for two main alternatives, namely LPG and charcoal stoves. A combination of conditional logit and mixed logit models were conducted to understand trade-offs inherent to household stove choice behavior and preference. For objective (c), a sustainability assessment framework was developed to assess the social, economic and environmental impacts of stove adoption. Mixed method approaches are used to establish patterns, both between stoves and across the enumeration transect zones.

For objective (a): Due to the radically different roles of the interviewed stakeholders and unique interest in the clean cooking value chain, there is a broad variation in their perspectives about specific drivers and barriers of stove adoption. Despite this variation, there is a good level of consensus about the main barriers and impacts of clean cooking options in Kenya. Some of the identified and interconnected factors that affect stove adoption include stove affordability, awareness, behavioral change, reliable supply/distribution networks, business financing mechanisms, stove design and performance, community involvement, and quality assurance. The study identifies that such points of convergence can be mobilized to coordinate efforts in the otherwise fragmented institutional landscape.

For the first part of objective (b): the estimated factors with the highest total effects on adoption of biogas stoves include: income, number of livestock, farm size, credit access, education and gender of the household head. For improved biomass stoves, agroforestry practices, gender, income, credit access, education level and participation in social groups had the highest total effects on adoption. The results further indicate that adoption of improved biomass stoves significantly increase by 4.2% $(p<0.05)$ with each additional kilometer walked from the homesteads to the most frequent fuelwood collection woodland. From a gendered perspective, the results suggest that, despite

the fact that women bear disproportionately the burden of fuelwood procurement and cooking tasks, they were found to have limited access to productive resources and less income as compared to males. Nonetheless, the results suggest that women have better opportunities for adoption in terms of access to credit services and participation in social groups.

For the second part of objective (b): the discrete choice analysis results signify respondents' preference for the modern, LPG stove as compared to charcoal stove alternative. However, the estimation results further suggest that a given increase in stove price, monthly fuel usage cost and indoor pollution reduces respondents' probability for LPG preference. Based on the relative magnitude of the coefficients, fuel usage cost was found to affect decision making 3 times more than the stove price. The magnitude of this utility is not universal for all but varies by geographical location and intra-household factors.

For objective (c): Adoption of improved biomass stoves was found to reduce the average daily per capita fuelwood consumption by about 40%. The population strata located at close proximity to the forest had a higher per capita consumption than those farther away. In terms of GHG emissions, improved biomass stove and biogas stoves had an emission reduction potential of 1.97 and 5.03 tCO_2e/household/year, respectively. When it comes to economic impacts, improved biomass stoves and biogas stoves were found to reduce the opportunity cost of unpaid time investment by about 26% and 48%, respectively. From an economic feasibility perspective, the analysis suggests that households relying on commercial fuelwood can save an estimated average of USD 54.68/year in Muranga and USD 64.21 in Kiambu and enjoy a discounted payback period of about 8 months for a USD 15 stove investment. Biogas adoption was found to provide an average annual saving of about USD 164.20 at a discounted payback period of 8.23 years for a USD 1000 stove investment. For social impacts, probit regression models were conducted to estimate the probability of prevalence of self-reported respiratory health symptoms. The results suggest a significant protective effect on prevalence of respiratory symptoms by cooking outdoors and in kitchens installed with appropriate ventilation structures.

From a policy perspective, this study suggests that, effective transition towards universal clean cooking can be achieved in Kenya by fostering measures to: (a) enhance multi-stakeholder and cross-sectoral collaboration; (b) implement appropriate financing mechanisms and economic incentives; (c) adopt local-specific policy approaches and stove dissemination activities; (d) facilitate awareness and behavioral change among stove users; and (e) strategize clean cooking technologies as cost-effective catalysts to deliver impact and interlinkages across multiple SDGs.

This committee unanimously agreed to award the degree of Doctor of Sustainability Science.

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