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Research paper

Deforestation and biomass fuel dynamics in Uganda

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ABSTRACT

Forests are, and will remain for decades to come, a critical source of domestic energy for households in East Africa. Deforestation threatens to alter the supply of biomass available to households. We use remote sensing and longitudinal household data to understand the relationship between agriculture-led deforestation and household energy choices in Uganda. Our hypothesis is that rapid deforestation and associated biomass stock depletion affects the type, quantity, and quality of fuels used by households. We analyze land use changes characterizing deforestation and forest degradation at 500-m spatial resolution. Using two waves of survey data for 451 households, we describe changes in the type, quantity, and source of biomass fuels used. We estimate net losses of 4.51 billion kg or 26% of available air-dry biomass over an 8-year period in 5-km buffers surrounding the study villages. We estimate a series of panel mixed-effect regression models to test whether reduction in biomass availability affects fuel choice and find that lower biomass availability is associated with an increase in fuel sourced from non-forest areas, use of crop residues as a cooking fuel, and time to collect fuel. We find that households are transitioning from fuelwood sourced from forests to fuelwood sourced from areas with much less available and lower quality biomass. We find limited evidence that investment in tree planting is replacing natural forests as a source of high quality biomass fuel. Our findings have implications for both human and environmental health particularly in biomass dependent and population dense settings in sub-Saharan Africa.

1. Introduction

More than in any other region, households in sub-Saharan Africa (SSA) depend on biomass for domestic energy supply, adversely affecting human health, environmental goods and service provision, and contributing to global and regional climate change [5,9,10,17,40,51,64]. The absolute number of people dependent on biomass fuels in SSA will increase through 2030 [22,62], suggesting that policymakers should pay careful attention to the factors influencing supply, demand, and distribution of biomass fuels. This issue is particularly salient in East Africa where approximately 95% of the populations of Burundi, Ethiopia, Rwanda, Tanzania and Uganda use solid fuels for cooking and heating, with no movement in relative rates of biomass use in recent years [21]. The persistence of biomass fuels is partially due to slow development in markets for modern fuels (e.g., electricity and liquid petroleum gas) and efficient/clean cookstoves, and a lack of information about the individual and social benefits of switching stoves and fuels [43,53]. High capital costs combined with poor infrastructure further inhibits the adoption of modern fuels and technologies. Decentralized energy systems for electricity may be spreading rapidly across SSA, but electrification suitable for cooking lags significantly behind electrification of household lighting [3].

With a variety of biomass fuels available to meet household energy needs (e.g. fuelwood, charcoal, crop residues, and dung), few studies have explored how supply-side factors affect fuel choice [39]. While demand for biomass fuel grows in sub-Saharan Africa, rapid land use change is affecting the supply of high quality biomass leading households to shift collection away from fully stocked forests toward degraded forests, agricultural plots, and fallows that yield lower per hectare quantities of biomass [2,15]. In addition to lower yields, biomass sourced from land uses other than fully stocked forests is typically of lower quality. Low quality

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biomass has lower energy densities and higher concentrations of organic materials, leading to incomplete combustion and increased particulate matter emissions [37,45,54]. Fuel type, quantity, and quality (e.g., moisture content, size etc.) influence the generation of harmful pollutants that comprise household air pollution.

Laboratory tests confirm the effect of biomass fuel quality on emissions. [37] conducted a comprehensive laboratory-based study of emissions from a large number of stoves in which fuel type varied. In general, stoves that used charcoal produced higher CO emissions and lower PM emissions than stoves that used fuelwood. [11] also found that CO emissions from wood fired stoves were lower than from charcoal fired stoves. [58] compared emissions when using wood pellets and crop residues in five configurations of natural-draft, top-lit up-draft (TLUD) semi-gasifier cookstoves and found that, in general, emissions from residues were much higher than for wood pellets. Cooking fires with wet fuels produce more products of incomplete combustion including CO and PM2.5 [1,26], and higher emissions of aerosols or VOCs [44]. [37] found that wet fuel produced higher CO emissions than dry fuel for most stove-fuel combinations, and wet charcoal produced higher PM emissions for most stoves.

Accordingly, changes in the supply of locally available biomass fuels, and associated declines in fuel quality have implications for human welfare affecting health through exposure to household air pollution. In Uganda, [34] found that increased reliance on low quality fuelwood sourced from non-forested areas (i.e., fallows, agricultural lands, and bushlands) was associated with a higher incidence of respiratory infection, particularly for children under five years who are often with women when they cook. A marginal increase of 100 kg of non-forest sourced fuelwood used to cook meals led to a 2.4% increase in respiratory infections controlling for other factors. Similarly, [14] find that increased reliance on low quality fuelwood or crop residues is associated with a higher prevalence of symptoms of cardiopulmonary and neurologic health problems in Malawi. Deforestation and forest degradation leading to declines in biomass also affects economic productivity by constraining time use and affecting labor allocation. Women and children often spend more time collecting fuels and cooking. Additionally, reductions in number of meals cooked, and changes in the type of foods that are prepared [4,13,63] can affect overall food security. Strategies for adapting to biomass scarcity include walking longer distances to collect fuelwood, fuel switching or changing the portfolio of fuels used by the household (as per our analysis), and using more efficient cookstoves [13,43].

We explore the ways in which reliance on solid fuels, including fuelwood of varying qualities, charcoal, and crop residues, is affected by land use change dominated by transitions from land with very high biomass density (e.g. fully stocked tropical forests), to much lower biomass density uses (e.g. degraded forest, agricultural lands, fallows, grasslands etc.). Specifically, we estimate reductions in above ground biomass observed over an eight-year period (2003–2011) in western Uganda, a region characterized by heavy biomass reliance, high rates of population growth, rapid land use change, and commensurate biodiversity loss [47]. We examine changes in the type, quantity, and source of biomass used by rural households, and explore the relationship between biomass supply dynamics and household fuel use. We leverage heterogeneity in baseline conditions in forest cover, forest governance, and migration patterns to understand observed trends. Several researchers have highlighted a lack of data on fuelwood harvesting trends and how they relate to land cover and land use dynamics [18,25,56]. Insights into the combined spatial and behavioral dynamics of woodfuel supply and demand are needed [24,42] (c.f., [33]). We seek to fill this gap.

2. Material and methods

2.1. Study area

The study villages fall within three sites spanning seven districts in west central Uganda covering a large geographic area with approximately 300 km between the southern and northern most villages. Livelihood strategies in the study area fall into five main categories: agriculture, livestock husbandry, collection of forest and wild products, wage labor, and small business. Dominant cropping systems include maize, bananas, and coffee. Additionally, some households in the study area have invested in planting fuelwood trees, primarily *Eucalyptus* species. Smallholders keep cattle, small ruminants and poultry in extensively managed crop-pasture systems [41]. Land holdings in the area are relatively small, averaging 2.65 ha per household. The Bugoma and Budongo study areas have undergone rapid settlement over the past 15 years, largely by migrants from land scarce Kabale District in southwestern Uganda (Bugoma), or by people from northern Uganda fleeing conflict (Budongo). Table 1 highlights population changes across districts and study villages in the 2002–2014 census periods. Buliisa, Hoima and Kibaale Districts experienced above average population growth between 2002 and 2014. Mean annual rainfall in the region is approximately 1.321 m per year [65]. Altitude ranges from 1000 to 1800 m above sea level.

A noteworthy distinction in our three study areas is natural resource governance regime. The southernmost site includes six villages adjacent to Rwenzori Mountains National Park (RMNP). While the District Forest Service (DFS) is officially responsible for overseeing land and forest resource use outside of RMNP, the Uganda Wildlife Authority is the *de facto* advisor on issues related to land use both within and outside RMNP. A major focus of their efforts is enforcement of use rights within the park. Land ownership outside of the park is dominated by customary land tenure. The Bugoma site is governed by the poorly resourced District Forest Service, which has very limited engagement in household-level land use decisions. Their major function is regulating timber harvesting, which they do with limited success [35]. The majority of forested land is privately owned, and falls under mailo, customary, freehold and leasehold tenure arrangements. The six villages in the Budongo site are adjacent to the Budongo Central Forest Reserve. As with the Rwenzori site, land use outside of the forest reserve is officially governed by the DFS, but the National Forestry Authority (NFA), responsible for managing and regulating central and local forest reserves has a *de facto* governance authority in the site. Their focus is on regulating use of resources in the reserve, which includes regulating a booming illegal timber trade. UWA, the DFS and the NFA represent the three institutions empowered under Uganda's 2003 forest sector decentralization reform to manage the nation's forests [29].

On forests and lands outside of gazetted areas, irrespective of tenure status, land owners are permitted to harvest fuelwood for subsistence use with no permissions or restrictions. Collection of fuelwood for subsistence use from forests or land owned by others is allowable with permission from the landowner. Charcoal production on own or other's land officially requires permission of the relevant District Forestry Officer who issues permits on a quota system. Both the number of permits and quantity of charcoal produced per permit are restricted. Within national parks and central forest reserves there are restrictions on collection of fuelwood, limited to subsistence use, and often limiting collection to those who live in villages adjacent to the protected area. Charcoal production is prohibited in gazetted areas [27].