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Nexus of energy use, agricultural production, employment and incomes among rural households in Uttar Pradesh, India

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ABSTRACT

This study analyzes the nexus issues of energy use, agricultural production, income and employment among heterogeneous and interdependent rural households in Uttar Pradesh, India. We use an agricultural household dynamic programming model that includes two types of households differentiated by their socio-economic characteristics and that are linked through agricultural contracts. Households are also differentiated by their membership in terms of men, women and children. The model simulates the effects of policies such as state subsidies for the purchase of solar panels, improvement in non-agricultural employment opportunities, and combinations of the two, as they are suggested to improve energy supply and reduce trade-offs in energy use. The model results indicate that households improve energy use patterns by using solar panels; yet, adoption of such technology is conditional on state subsidy levels of 50% and 80% for the purchase of solar panels for farming and domestic purposes respectively. Subsidies for solar panels together with improvement of off-farm work increases off-farm employment levels and income of the poorer household, however, this policy reduces agricultural production. In addition, the wealthier household incurs losses from improvement in non-agricultural employment opportunities due to reduced labor availability for farm operations.

1. Introduction

Worldwide, residential consumption accounts for about 30% of all end-use energy and nearly 2.6 billion people rely on bioenergy uses (IEA, 2013), particularly in rural areas of developing countries. Energy production is linked with other sectors that influence public welfare (Howells et al., 2005). Projected increase in the demand for agricultural commodities by 60–70% over the next 40 years due to global population growth will lead to increased competition for resources between agricultural and bioenergy production (FAO, 2012). Accordingly, increased use of bioenergy may reduce food crop output and thereby negatively affect food security (Bryngelsson and Lindgren, 2013). Also, increase in bioenergy production is expected to impact the employment composition of households and might reduce livelihood activities (Djanibekov et al., 2013). Moreover, trade-offs could exist between energy production and income generating activities, greenhouse gas emissions, and air pollution (Duflo et al., 2008; Mirzabaev et al., 2015).

Several policy options intended to improve household energy production have been analyzed with consideration of the importance of the nexus among energy production and various other dimensions, including: food production, employment, income generation, and environment (Jebaraj and Iniyan, 2006; Mirzabaev et al., 2015). For example, producing energy using renewable technology such as solar panels may increase household income and reduce CO_2 emissions (Hiremath et al., 2010). Yet, rural households in developing countries may not have sufficient financial resources to invest in the purchase of solar panel systems. To incentivize the adoption of alternative energy sources, state support in the form of subsidies that reduce associated costs might be necessary (Frondel et al., 2010). In addition, policy that contributes to improved non-agricultural employment opportunities can mitigate trade-offs between bioenergy and food production, and would also help diversify rural household income streams (Chen et al., 2006).

Most of the studies that have considered policy approaches for addressing the nexus of energy production with other dimensions were based on aggregated analysis approaches (Bryngelsson and Lindgren, 2013; Frondel et al., 2010; Gebreegziabher et al., 2013). However, aggregated approaches usually focus on analyses of markets and entire economy of a country and do not take into account household specific details and heterogeneity among households. Disaggregated level of

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analysis allows us to explore the impacts of energy use changes on various other dimensions of household activities and especially on different types of households and their members (Villamor et al., 2014a; Scheurlen, 2015; Djanibekov and Villamor, 2017). At the household scale, heterogeneity is manifested within membership and the responsibilities and activities of individual household members (Gasson and Winter, 1992). For example, in developing countries women are usually responsible for sustaining household energy and food provision (Villamor et al., 2014b), accordingly, changes in energy use are likely to influence labor activities among women and thus affect the energy use pattern and food security of the household (Arndt and Benifica, 2011). In addition, there is heterogeneity among rural households (e.g., differences in local socio-economic status, the scale and types of farming activities). As a result of such differences, changes in energy production and use can have differential effects at the household scale. For instance, Wang et al. (2016) found that the adoption of improved energy sources can increase overall societal welfare, yet socio-economic differences among households need to be considered due to variability in the adoption of such sources among households. In particular, poor households may not be able to afford alternative means of meeting their energy demand (Isaac and van Vuuren, 2009). Additionally, poor households tend to be disproportionately affected by energy and food production trade-offs, as well as by changes that affect income generating activities (Chen et al., 2006).

More importantly, consideration of heterogeneity among rural actors allows us to capture direct and indirect effects of energy production changes and the nexus among energy production and other sectors. Such effects can occur due to interdependency of households. For example, in developing countries rural households usually interact and may influence each other's agricultural activities through contracts intended to complement each household's farming activities through the provision of resources (e.g., Otsuka et al., 1992; Veldwisch and Spoor, 2008; Djanibekov et al., 2015). Such contractual interactions may lead to changes in energy production for one household type (or changes in policies and technologies targeted for one rural household demographic) and have indirect effects on other household types. Gebreegziabher et al. (2013) found that investment in bioenergy capacity not only benefits the welfare of poor households, but also indirectly benefits other households through labor relationships with the primary beneficiary households. Djanibekov et al. (2013) revealed that increased bioenergy production on large-scale farms may reduce energy use expenditures and improve incomes of hired labor through agricultural contracts.

To our knowledge, previous studies have not simultaneously considered the nexus of energy use and production with other aspects of household welfare along with heterogeneity within and among households and their interactions. To address this research gap, we use the case of Uttar Pradesh province, India, where rural households highly depend on traditional bioenergy for meeting energy demand and on farming for food consumption and income generation (Census of India, 2011). Using the agricultural household dynamic programming approach, we modelled two types of rural households of Uttar Pradesh that differ in socio-economic characteristics (i.e., poor and rich) and that are interlinked through labor-wage and irrigation supply-payment contractual arrangements. We further differentiate household membership in terms of men, women and children. This modeling framework allows us to investigate energy use, agricultural production, employment in both agricultural and non-agricultural activities, direct and indirect effects on households, and household gains or losses affiliated with introduced policy changes. We analyze policies such as state subsidies for the purchase of renewable energy equipment (e.g., solar energy options), improving off-farm employment opportunities for households, and combinations of the two, because such policies have been suggested for improving energy production and reducing related trade-offs for rural households (e.g., Chen et al., 2006; Frondel et al., 2010; Padilla and Serrano, 2006). The objectives of this study are: (1) to investigate the effects of policy changes with respect to the nexus of energy use and agricultural production, employment and income, while taking into account heterogeneity among household membership and types as well as interactions between households; and (2) to identify policies that improve livelihoods of heterogeneous households considering direct and indirect effects of these policies within the energy use nexus.

2. Methods

2.1. Study area

The study area is in the Uttar Pradesh province of India. We selected this area due to the results of the National Sample Survey 66th round in 2009–2010 indicating that dependence on traditional bioenergy in Uttar Pradesh is among the highest across all regions in India, and also because this province has one of the lowest centralized energy supply to households in the country (Census of India, 2011). The economy of the province is dominated by agricultural production, which accounts for about two-thirds of the provincial labor force (Singh, 2014). The province has a population of 199.58 million (Census of India, 2011). Predominant land uses are potato, wheat, rice, sugarcane and mustard cultivation (Census of India, 2011), primarily for household subsistence purposes (i.e., food consumption, fodder for livestock) and surplus is traded in local markets. Households are not provided sufficient energy from the state grid for meeting needs related to cooking, heating water, lighting and operating electrical appliances. Households usually satisfy their energy demand through combustion of bioenergy sources such as dried livestock dung, crop by-products, fuelwood, as well as with alternative sources such as solar panels, biogas, liquefied petroleum gas (LPG), kerosene, and batteries. Information on household energy source use is summarized in Table S.A.1 in Supplementary material A.

2.2. Data sources

Our main data source is a survey of 400 rural Uttar Pradesh households. The survey of households was conducted between February and June 2015. We undertook three sampling steps to determine household selection. In the first step, we selected districts based on consideration of the variance associated with socio-economic and energy systems. For this task, a district level dataset was created based on the following characteristics: per capita net district product; percentage of primary sector in net district product; population density; percentages of households that use fuelwood, livestock dung, crop residues, and LPG for cooking; electricity from the centralized grid; biomass surpluses at the district level; and the percentage area of wheat and rice production and their respective yields. We applied a statistical clustering analysis to the database to identify district clusters and then randomly chose four districts from among the clusters. The selected study districts are: Mathura (27°14′–27°58′N, 77°17′–78°12′E), Moradabad (28°16′–28°21′N, 7°4′–7°9`E), Rae Bareilly (25°49′–26°36′N, 81°34′–100°41′E), and Sant Kabir Nagar (26°47′–26°79′N, 83°3′–83°3.45′E).

In the second step, we selected villages from within the identified districts. We prepared lists of villages within each district based on Census of India: Uttar Pradesh (2011). We assumed that all villages of the identified districts shared the characteristics used to designate the district clusters. Two villages were randomly selected from each district for a total of eight villages. In the third step, we chose sample households by applying a systematic sampling technique used by Levy and Lemeshow (2008). To employ this technique we began at the center of each village, chose a random direction and then randomly selected a household in that direction. Afterwards we selected another household located in each direction. Selected rural households were then surveyed for information on demography, income sources, expenditures, asset