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Forests, fuelwood and livelihoods—energy transition patterns in eastern Indonesia

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HIGHLIGHTS

- We model household energy use patterns of forest margin communities in Indonesia.
- Fuel subsidy reform increased fuelwood demand for processing agricultural products.
- Household fuel choices are affected by opportunities to sell fuelwood.
- Energy transition of households does not necessarily affect forest conditions.
- Energy alternatives to small industries are needed to improve forest conditions.

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ABSTRACT

The central thesis of the energy ladder model is a unidirectional transition from primitive to advance fuel with increased affluence of households. Although now largely discredited, this assumption remains a foundation of *laissez-faire* policies that anticipate energy transition resulting spontaneous forest recovery with economic development. Our results suggest that such policies can undermine broader policy objectives and actually worsen forest conditions in rural Indonesia. Based on a case study of forest margin communities in eastern Indonesia, we demonstrate that fuel subsidy reform did little to reduce rural household demand for fuelwood, while dramatically increasing fuelwood demand for processing agricultural products. Our results show how household decisions related to fuel sources are affected by non-economic considerations and external factors, such as opportunities to sell fuelwood. We argue that policy interventions that encourage energy transition of households do not necessarily improve forest conditions, as household fuelwood use may be a symptom, rather than a driver of deforestation and forest degradation. Thus policies to improve forest conditions should focus more on addressing the market environment of forest-margin communities, providing energy alternatives to small industries that are often the larger consumers of fuelwood.

1. Introduction

Wood has traditionally been considered a sustainable source of energy. Several developing countries have the potential for producing wood energy safely and sustainably, with relatively low investment and risk, while developing their national economy and creating jobs in rural areas (FAO, 2010a). However, this potential has not been realized due to poor forest management, inability to regulate illegal operations, and lack of reliable data for adequate planning (FAO, 2010a). In tropical Asia, emissions from forest degradation due to unsustainable fuelwood harvest could account for 25–42% of total forest emissions (Griscom et al., 2009). In addition to carbon dioxide emissions from deforestation and land degradation, emissions of black carbon, a portion of soot from inefficient biomass burning, are estimated to be 18% of global black

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carbon emissions (Bond and Sun, 2005). Black carbon, radiative forcing, has particularly serious climate impacts, in addition to being harmful to human health (Foell et al., 2011; Ramanathan and Carmichael, 2008). The International Energy Agency (IEA) estimates that as of 2011, 1.9 billion people in developing Asia (or 51% of the population) still rely on traditional biomass, including fuelwood, as their primary source of energy (IEA, 2013). Over half of the population relying on fuelwood lives in India, China and Indonesia; however, the total forest area in India and China has increased in recent years with economic development and strong government-led programs and policies (Mather, 2007), including the creation of large scale wood fuel plantations (FAO, 2010a).

Indonesia, the world's fourth most populous country, is still experiencing one of the fastest rates of deforestation in the world (more than 1000 km^2/year; Hansen et al., 2013). Indonesia is emerging as one of the major beneficiaries of global negotiations to mitigate climate change through improved forest management, especially related to REDD+[1] (Cerbu et al., 2011). So far, Indonesia has received the largest portion of funding from both multilateral and bilateral channels (Simula, 2010). The forestry sector is expected to achieve more than 50% of its ambitious greenhouse gas emission reduction target, which is 26% below business-as-usual projections by 2020 (Cerbu et al., 2011). However, the extent of unsustainable fuelwood collection and their effects on forest conditions in Indonesia is largely unknown (Budya and Arofat, 2011). Emissions from forest degradation remains as a controversial topic in global climate negotiations (Griscom et al., 2009).

Since 2005, Indonesia has been promoting energy transition from kerosene to more efficient, less subsidized liquefied petroleum gas (LPG) in households and micro-businesses (IISD, 2014). There are many reasons to encourage household energy transition with policy interventions, including human health (WHO, 2014) and social/gender inequity concerns (Cooke et al., 2008; Köhlin et al., 2011). Although clean household energy is expected to ensure environmental sustainability (WHO, 2014), our understanding about the links among energy transition, fuelwood consumption and forest conditions is limited (Heltberg et al., 2000; Lewis and Pattanayak, 2012; Pattanayak et al., 2004). To design appropriate policy interventions to encourage energy transition and/or improve forest conditions, we must be able to discern the potential impacts of such interventions. Therefore, we ask in this paper: (1) if household energy transition in forest margin communities affects forest conditions, (2) to what extent their energy choices are due to the internal characteristics of household and external factors, including fuelwood markets, and (3) what are the extent of non-domestic fuelwood consumption and its potential effects on forest conditions.

Using a case study in eastern Indonesia, we first examine household energy use patterns and factors affecting the energy choices of rural households in forest margin communities to discern the direct effects of a national policy intervention to encourage energy transition. We then assess the extent of fuelwood demand for processing agricultural products, using tobacco curing as an example to portray the unintended consequences of the policy intervention.

[1] The United Nations Framework Convention on Climate Change (UNFCCC) defined REDD+ as "policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries" (UNFCCC, 2010).

2. Methods

2.1. Literature survey—household energy transition, fuelwood consumption, and forest conditions

Until recent years, academic interest in fuelwood issues has steadily diminished, after the overall consensus was reached that previous concerns for supply gap (discrepancies between fuelwood demand and potential supply) had been exaggerated (Arnold et al., 2003; Arnold et al., 2006). Our own search on the Web of Science™ revealed that the number of peer-reviewed publications related to fuelwood[2] decreased over time until 2007. However, expanding interest in the climate mitigation potential of the forestry sector has renewed interest in fuelwood as a renewable energy source, and in the effects of fuelwood use on forest conditions and resulting carbon emissions.

Household energy choices and transition patterns have been an active research area for more than three decades with much debate about the factors affecting fuel choices and transition (van der Kroon et al., 2013). The 'energy ladder" model conceptualizes a linear transition of household fuel choices from *primitive* fuels (e.g. fuelwood, agricultural and animal waste), to *transition* fuels (e.g. charcoal, kerosene, coal) to *advance* fuels (e.g. LPG, electricity, biofuels) (e.g. Hosier and Dowd, 1987; Leach, 1992; Smith et al., 1994). The conventional wisdom of steady upward climb on the energy ladder with increased affluence has been largely contested by growing empirical evidence, especially for rural households (e.g. Heltberg, 2004, 2005; Hiemstra-van der Horst and Hovorka, 2008; Kammen and Lew, 2005; Masera et al., 2000). Masera et al. (2000) first proposed a multiple fuel choice model, "energy stacking", where households choose to consume a portfolio of different energy options, rarely completely abandoning the old technology at once. They also argued that household fuel choices are not purely economic decisions, that they are often driven by culture and tradition. A study from central Java in Indonesia showed that higher income households have more energy options and choose from a variety of energy sources (Andadari et al., 2014). Thus, more opportunities for energy stacking do not necessarily imply less fuelwood consumption.

Despite various research efforts, household energy use patterns and the factors affecting them are still poorly understood, especially in rural areas in the developing world (Kowsari and Zerriffi, 2011). After extensive reviews of energy studies over the last three decades, Kowsari and Zerriffi (2011) summarized the factors determining household energy choice in two broad categories: *Endogenous* factors (household characteristics) including: (1) economic characteristics, such as income, expenditure, land ownership (e.g. Barnes et al., 1996; Leach, 1992; Pachauri, 2004), (2) noneconomic characteristics, such as education, family size, gender and age composition (e.g. Arnold et al., 2006; Bluffstone, 1995; Cooke et al., 2008; Dewees, 1989), and (3) behavioral and cultural characteristics, such as preferences, attitudes, beliefs, and social status (e.g. Farsi et al., 2007; Gupta and Köhlin, 2006; Heltberg, 2005; Masera et al., 2000; Wang and Feng, 2003). *Exogenous* factors (external conditions) including: (1) physical environment (e.g. Bhatt and Sachan, 2004), (2) policies on energy, subsidies, markets, and trade (e.g. Dube, 2003) (3) energy supply factors (e.g. Heltberg, 2005; Leach, 1992), and (4) energy device characteristics (e.g. Leach, 1992). However, the link between higher income and cleaner fuel has been overemphasized in the literature, which may have obscured the effects of other factors (Hiemstra-van der Horst

[2] Three-year moving average of the number of peer-reviewed articles that contain fuelwood, firewood or woodfuel on the title peaked at 13.3 in 1985 then declined to 5.7 in 1996, then jumped to 21–25 since 2011.

and Hovorka, 2008; Kowsari and Zerriffi, 2011). The extent of influence from different factors is highly dependent upon local context, thus policies to increase the implementation of new fuel sources or technologies must “address barriers to accessibility, affordability and acceptability” within the local context (Foell et al., 2011, p. 7493). For example, cultural and social preferences for fuelwood, despite relatively higher costs, were observed in Mexico (Masera et al., 2000), Guatemala (Heltberg, 2005) and India (Gupta and Köhlin, 2006). However, fuelwood demand was more clearly associated with increased income and livelihood changes in Nepal (Bluffstone, 1995), China (Wang et al., 2012), and Uganda (Lee, 2013).

For rural households and small businesses in many developing countries, fuelwood is important for processing a variety of agricultural products (e.g. coffee, tea, tobacco and coconuts) and for manufacturing bricks, lime, ceramics and certain textiles (FAO, 2010a). Fuelwood is also important in the local food supply chain for restaurants, catering services and street venders (FAO 2010a). Thus, it is also important to recognize the fact that rural households collect fuelwood not only for domestic consumption, but also to sell (Hiemstra-van der Horst and Hovorka, 2009; Khare et al., 2000; Townson, 1995). Economic studies employing a static household utility maximization model tend to assume complete rational choices based on internal household characteristics with no market trade of fuelwood (e.g., Pattanayak et al., 2004). In Indonesia, there are estimated 56.5 million small businesses, operating mostly unregistered in the informal sector (Tambunan, 2014). The energy demand of these small businesses is largely unknown due to a lack of data (Tambunan, 2014).

2.2. Case description—Indonesia’s domestic energy subsidy reform

Indonesia had heavily subsidized the retail price of petroleum fuels since 1967 (Dillon et al., 2008). The government had raised subsidized prices by an average of 125% in 2005, 28.7% in 2008, 44.4% in 2013, and again by 30.8 % in 2014 (IEA, 2008; IEA, 2009; IISD, 2014; Rambu Energy, 2014) [3]. Even with this series of reductions, Indonesia’s spending on energy subsidies increased from 16% in 2010 (IISD, 2012) to 25% of total government expenditure in 2013, exceeding Indonesia’s spending on defense, education, health and social security combined (IISD, 2014). Removing subsidies on kerosene was intended not only to reduce the burden of the energy subsidy on national spending, but also to reduce its consumption and free up petroleum from kerosene production for more profitable products (e.g., jet fuel) (Budya and Arofat, 2011). Bringing domestic fuel prices more in line with international energy prices was expected to encourage energy conservation, a shift to cleaner sources of energy, and reduced volatility of the overall economy tied to international energy markets (IISD, 2012). Removing subsidies was expected to affect high-income households more than the poor (as the wealthy consumes more energy), and to reduce greenhouse gas emissions, local air pollution, and resource depletion from fossil fuels (IISD, 2012). Removing energy subsidies was also expected to reduce Indonesia’s CO_2 emissions by 5.8 % by 2020 (Yusuf et al., 2010).

A massive government-led energy program, known as the energy mega-project, was launched to replace kerosene as the primary fuel for household cooking and micro-businesses to more efficient, less subsidized liquefied petroleum gas (LPG). The program included free distribution of containers, cylinders, and stoves for LPG, encouraging the transition of 50 million households from 2007 to 2011 (Budya and Arofat, 2011). An earlier study predicted that change in the kerosene price would have a negligible effect on the demand for fuelwood, especially in rural Indonesia where kerosene was at the time primarily used for household lighting (Pitt, 1985). However, encouraging rural households to cook with cleaner and more efficient LPG was expected to reduce pressure on national forests (Budya and Arofat, 2011). There is some evidence to suggest that the program was indeed successful in encouraging conversion from traditional biomass use. IEA predicted in 2006 that people relying on traditional biomass would increase in Indonesia, from 156 million in 2004 to 180 million by 2030, without successful new policies and programs (IEA, 2006). The statistics later showed a continuous decline to 124 million in 2009, and 103 million in 2011 (IEA, 2011; IEA, 2013).

However, the energy mega-project may not provide such a straightforward story of successful government-led energy transition. Although the total number of households relying on traditional biomass is decreasing, Andadari et al. (2014) showed that the project had failed to substantially reduce the number of energy-poor people, and actually increased the use of multiple fuel types, especially in rural areas. They also demonstrated that the number of households using fuelwood in combination with other fuel types had increased in both rural and urban areas after the megaproject (Andadari et al., 2014)

2.3. Study area

International attention on forest conservation in Indonesia has been more focused on the western part of the country, particularly the islands of Kalimantan and Sumatra, and relatively little attention has been paid to eastern Indonesia (CSIRO, 2011, Russell-Smith et al., 2007). A case study from the eastern part of Indonesia can illuminate the impacts of the energy mega-project in an area where energy prices remain high and unpredictable due to long-distance transportation of fuel and a lack of local infrastructure (Tambunan, 2014).

The study area includes the forest margin communities around the Rinjani Barat Forest Management Unit, located in western and northern Lombok, one of the two main islands in the province of West Nusa Tenggara (*Nusa Tenggara Barat*, or NTB) in eastern Indonesia (Fig. 1). According to a recent analysis of Landsat images, the forested area of Lombok has decreased 28.6% from 1990 to 2010 (Bae et al., 2014). By comparison, Indonesia’s national average is 20.3% during the same period (FAO, 2010b). Lombok is one of the most densely populated places in Indonesia (683 persons/km^2, compared to the national average of 129 persons/km^2; BPS, 2012). Based on the 2010 Population Census (BPS NTB, 2011), seventy percent of the population of NTB resides in Lombok, which is about a quarter of the total land area of the province. Economic opportunities are limited to agriculture (23% of GDP and 47% of employment) and the mining and quarrying sector (27% of GDP and 3% of employment) (BPS NTB, 2011). Lombok is a major supplier of flue-cured tobacco leaves, accounting for 17% of total tobacco production in Indonesia (BPS, 2012). NTB province ranked the second poorest among the 33 provinces in Indonesia, based on the Human Development Index (HDI), a measurement of the average achievement of life expectancy, education level, and per capita income. The latest figures (2011) indicate that the districts in the study area show the lowest HDI in NTB (North Lombok=60.93; West Lombok=62.50; NTB=66.23) (BPS NTB, 2011).

2.4. Data collection and the analytical framework

Primary data was collected in 14 locations in the study area through focus group discussions (FGD) and household surveys. A FGD is designed to engage a group of people from similar backgrounds in open conversations, in order to gain insights into a range of opinions and ideas (Bloor et al., 2001) During our FGDs,

[3] Indonesian government announced complete fuel subsidy elimination in January, 2015, except small subsidy on diesel (the Jakarta Post, 2015 (January 2)).

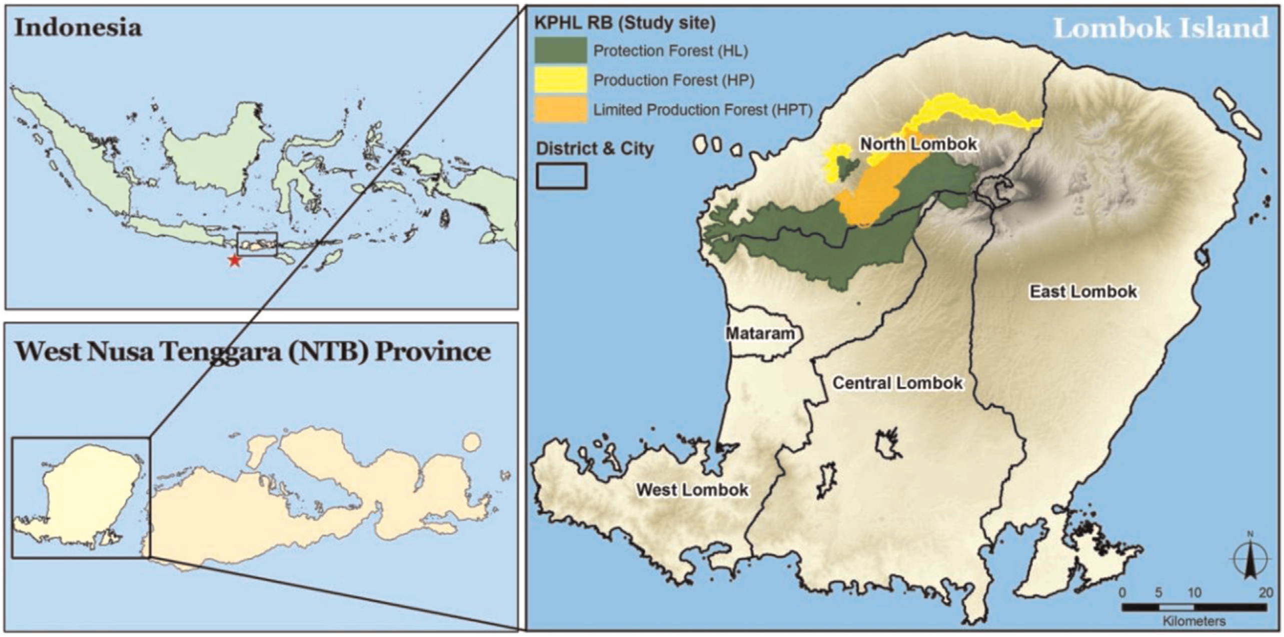

Fig. 1. Map of west Nusa Tenggara province and the study area (KPH RB).
Source: Korea Research Institute.

trained facilitators guided discussions among participants through the construction of shared village histories and participatory village mapping to estimate trend changes in terms of energy use, forest resources, livelihoods, consumption patterns, access to education and electricity, and to gauge community perceptions of livelihood needs and property rights. Each of the FGDs was attended by at least 25 participants, and we sought balanced representation in terms of age, livelihood activities and income levels, and local/indigenous people and migrants.[4] We examined FGD results in terms of historical changes, and behavioral and cultural factors affecting fuelwood consumption.

The questionnaires for the household surveys were developed based on FGD results, and used to quantitatively measure economic and non-economic characteristics of households and their use of forest resources, including fuelwood. We randomly selected 30 households from each site and collected 418 responses with all key demographic variables.

To understand the factors influencing individual households' energy choices, we applied logistic regression models to explain (1) probabilities of choosing energy types (Group 1: fuelwood-only, mixed sources[5], and gas-only models), and (2) probabilities of fuelwood source choices (Group 2: forests-only and garden-only models) (Fig. 2). For the second group, we eliminated fuelwood collection from a variety of sources to reduce the ambiguity of fuelwood source choices. Consistent with previous literature (Kowsari and Zerriffi, 2011), we explained these probabilities with various internal and external factors of the households.

Establishing the supply and demand chains for fuelwood harvested through illegal logging is beyond the scope of this study, and may require a very different research approach, including substantial criminal investigation. However, we can appraise the extent of fuelwood demand by analyzing the volume of fuelwood needed based on estimates of energy requirements for final products produced. In this case, we used tobacco curing as an illustrative example, since it shows both the magnitude of fuelwood demand for non-domestic uses and the effects of the removal of the kerosene subsidy. We reviewed reports and secondary data from government agencies, NGOs, a local university, and tobacco companies (e.g. Indonesia's Central Agency for Statistics, Fauna & Flora International/NTB, University of Mataram, and PT ELI). We also interviewed representatives of three major tobacco companies in Lombok to assess their perceptions of energy issues related to tobacco processing, and their strategies to addressing them.

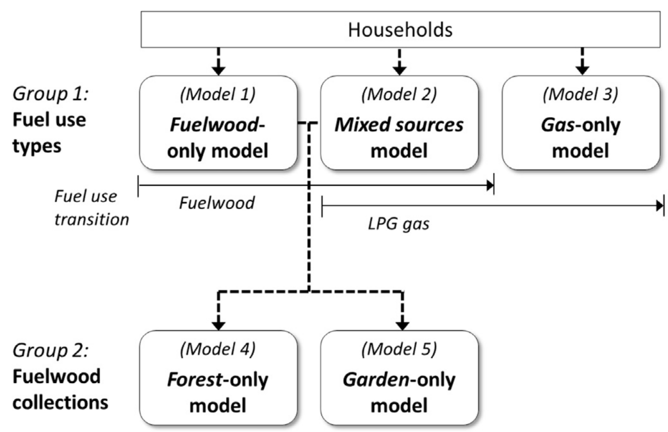

Fig. 2. Structure of the logistic regression models.

3. Results

3.1. Household energy choice—focus group discussions

During the focus group discussions, several themes of fuelwood collection and use patterns emerged. Most participants confirmed that they use woody biomass, including tree branches, palm fronds, dead wood and bamboo for everyday cooking, all of which they collect and/or buy from local markets. The most common

[4] We acknowledge that most of the FGD participants were men, and we did not conduct separate FGDs for women. This would limit our insights into different gender perspectives of fuelwood uses. We focused our discussion here on the forest uses of households level.

[5] Among 418 households, 20 households still used kerosene with fuelwood and gas, but no households used kerosene only. The mixed source group included a variety of energy sources.

source reported was agroforestry areas, often referred to as mixed gardens. Those species with dense biomass that require frequent pruning, such as coffee and cacao, provide an especially good source of fuelwood. Fuelwood is also collected from forest cultivation areas and primary forests. Forest cultivation and fuelwood collection from primary forests are illegal but these incidents are infrequently reported and offenders are rarely charged. For example, NTB province had 158 accused cases of illegal forest uses in 2002, of which only 16 cases resulted in sentencing. Numbers of both accused and sentenced have decreased steadily, to only 3 sentenced out of 15 accused in 2011 (Dinas Kehutanan Provinsi NTB, 2011).

On special occasions, such as weddings, funerals, and special holiday meals, extended families and neighbors often cook together for days at a time. Fuelwood is the preferred energy choice for these events. FGD participants reported that food cooked with fuelwood for these occasions is regarded as having a preferred taste. Some participants also reported that they do not use LPG because of fear of explosions.

We asked participants to profile different levels of wealth within their communities. They often characterized “poor” households as those consisting of landless laborers, with simple housing, no special cooking facilities, and those that rely solely on fuelwood. The “poor” were also described as those collecting fuelwood for sale. Those considered “well-off” were described as having a house with cooking facilities for LPG and electricity as well as fuelwood.

The shared history narratives revealed that all households used fuelwood for cooking up until the 1990s, when heavily subsided kerosene was introduced into the area. Limited adoption of kerosene for household cooking and lighting occurred, but most kerosene users converted to LPG during the last ten years. However, three villages reported that fuelwood sales were one of the most important sources of cash income (see large-scale fuelwood market in Table 1). These should be considered separately from small-scale fuelwood markets, where collection is mostly done by simple tools for domestic uses and the unused portion of fuelwood is sold to nearby markets (small-scale fuelwood market in Table 1). The average price for fuelwood is Rp. 5000 (USD 0.50) per bundle ($\approx$4 kg), which cannot be a significant source of income for small-scale operations. In the villages reporting significant income from fuelwood, trees are harvested with chain saws and carried out by trucks, and this work is often contracted through middlemen and outsiders. One village reported 5–15 truckloads (1 truck $\approx$ 5240 kg) of sales per day during the tobacco-curing season. In addition, about 1 to 2 truckloads of fuelwood are sold every weekend throughout the year to be used for weddings, funerals, and other special occasions.

3.2. Household energy choice—household survey

We found that about 80% of the households surveyed use fuelwood as their primary energy source: 52.7% use fuelwood as the only energy source for cooking, and 27.0% use a variety of energy sources, including fuelwood and LPG. The households using only LPG for cooking were 20.3% of those surveyed, although the LPG distribution program started nationally in 2007, and in 2010 in Lombok (Budya and Arofat, 2011). Among those households that use fuelwood, we found that 15.4% collect fuelwood only from forests, and 63.6% solely from agroforestry areas. The other 21% includes those who collect fuelwood from a variety of areas, as well as those who purchase fuelwood from local markets. Table 1 shows the descriptive statistics of variables employed in the analyses. The internal factors have been divided into economic and non-economic factors. We did not utilize direct variables representing behavioral and cultural attitude toward energy choices of individual households. However, perception on land tenure security, wealth indices and education can be indirect indicators of attitudes and the social status of households. Income from wives and children helps explain the opportunity costs of fuelwood collection, because women and children are often responsible for gathering fuelwood for domestic consumption. To avoid multicollinearity with other income and wealth variables, income from wives and children was introduced as a dummy variable. To characterize external factors affecting energy choice, we included accessibility to forest (reported as time to access forest), since distance, road conditions, and topography are all important aspects of determining accessibility. We characterized the institutional setting of communities based on the number of government-led programs operating in these communities. Most of these programs are focused on poverty alleviation, and not directly targeted at energy use. Some of these social assistance programs were initiated to cushion the effects of energy subsidy reform on poor households (IISD, 2014). Accessibility to other energy sources and available energy devices were assumed to be more or less

Table 1
Descriptive statistics of variables.

Variable name	Variable description	Average	SD[a]	Data range
(*Household's internal economic variables*)				
Wealth index 1	Farm animal value in million Rupiah	5.26	16.81	0–19
Wealth index 2	No. of TVs, cell phones, refrigerators, and motorcycles	3.87	3.03	0–15
House condition indicators	Material quality of house roof and floor	15.18	2.53	0–20
Household total income	Incomes per month in million Rupiah	4.34	4.05	0.3–31.5
Forest cultivation area	Area of household's forest cultivation	55.27	65.37	0–400
Mixed garden area	Area of household's mixed garden	57.59	256.31	0–5,000
(*Household's internal non-economic variables*)				
Education	Years of education	5.86	4.59	0–19
Family size	No. of family members living together	2.98	1.34	1–7
Land tenure security	Household perception from 0 to 5	3.12	1.74	0–5
Income from wife or children	Existence of income from wives or children	0.39	*NA*	0–1
Cultivating pruning species	Households cultivating pruning species	0.50	*NA*	0–1
Gas stove	Existence of a gas stove in households	0.39	0.49	0–1
(*Household's external conditions*)				
Accessibility to forest	Time to access forests in hours	1.01	0.76	0.02–4
Government programs	No. of govt. social programs in the village	1.51	1.11	0–9
Large fuelwood markets	Existence of a large-scale market in the village	3.00	*NA*	0–1
Small fuelwood markets	Existence of a small-scale market in the village	6.00	*NA*	0–1

[a] Standard deviation (SD).

Table 2
Logistic regression models of household energy choice ($n=418$) (Group 1).

Variable names	Fuelwood-only model		Mixed sources model		Gas-only model	
	Estimate	Pr(> |t|)	Estimate	Pr(> |t|)	Estimate	Pr(> |t|)
Constant	5.37	0.00	−6.63	0.00	−3.94	0.00
(*Internal economic variables*)						
House condition*	*−0.16*	0.01	*0.19*	0.01	0.09	0.20
Value of livestock	−0.01	0.49	−0.01	0.11	*0.02*	0.01
Number of assets	−0.12	0.06	0.04	0.49	0.03	0.67
Monthly total income*	0.02	0.57	*−0.13*	0.00	*0.09*	0.02
Forest cultivation area	0.01	0.07	*0.01*	0.00	0.00	0.18
Mixed garden area	0.00	0.44	0.00	0.33	0.00	0.32
(*Internal non-economic variables*)						
Education*	*−0.12*	0.00	0.00	0.98	*0.14*	0.00
Family size	−0.04	0.67	0.01	0.95	0.10	0.44
Land tenure security*	−0.02	0.86	*0.24*	0.01	*−0.20*	0.03
Income from wife or children	0.08	0.78	−0.10	0.75	0.04	0.90
Pruning species*	*1.02*	0.00	−0.31	0.30	*−0.84*	0.02
Gas stove*	*−2.72*	0.00	*2.28*	0.00	*1.35*	0.00
(*External variables*)						
Travel time to forest	*−0.49*	0.01	0.32	0.08	0.11	0.63
Government programs*	−0.10	0.48	*0.31*	0.01	*−0.32*	0.02
Small fuelwood markets	−0.30	0.36	−0.19	0.57	0.57	0.09
Large fuelwood markets*	−0.48	0.20	*1.49*	0.00	*−2.52*	0.00
Log-Likelihood	−179		−183		−141	
McFadden R^2	0.38		0.25		0.33	

* Variables significant ($P<0.05$) in more than two models

similar among the forest margin communities surveyed. To characterize the market environment (i.e., opportunities to sell fuelwood), communities were grouped in three categories based on FGD reports: communities with large-scale fuelwood trade, those with small-scale fuelwood trade, and those with no reported fuelwood sales.

To understand the factors influencing the energy choices of individual households, we applied three logistic regression models (Table 2). Some of the results followed our general expectation. For example, better house condition showed strong influence on the likelihood of utilizing multiple sources of energy, although households with more cash income were more likely to use LPG alone. The most interesting findings were the influences of non-economic and external factors of the households on their energy choices. Our results show that better educated households were more likely to adopt the new and convenient energy sources. More secure land tenure also encouraged uses of more mixed energy sources, rather than gas alone. The cultivation of dense biomass species that require regular pruning may provide enough fuelwood for domestic use, and less incentive to seek out other sources of energy. Among 16 explanatory variables applied across the three models in Group 1 (Fig. 2), the ownership of gas stoves was the only variable that was consistently significant in all three models. Of course, the ownership of gas stoves is an indicator of LPG use, but more as part of mixed energy choices than LPG alone.

One of the most important findings was that household energy choices were strongly influenced by the external institutional and market environments. Our results revealed that recipients of social assistance programs (e.g., providing rice, health services assistance for education, and microloans) were more likely using mixed sources of energy than LPG alone. Small-scale fuelwood markets did not significantly affect household fuel choices. However, those communities with large-scale fuelwood markets were less likely to use gas as the only energy source and more likely to use mixed sources of energy.

Table 3 shows the factors influencing household choices for fuelwood collection areas, such as forest and garden. The households were more likely to collect fuelwood from forests only if they lived close to the forest and utilized cultivation areas inside the forest. Their opportunity costs of collecting fuelwood would be lower, both due to reduced travel time and the fact that fuelwood collection can be part of other activities related to forest cultivation. Economic factors as a whole did not show strong influence on the source of fuelwood collection, although having secondary

Table 3
Logistic regression models of household fuelwood source choice ($n=333$) (Group 2).

Variable names	Forest-only model		Garden-only model	
	Estimate	Pr(> |t|)	Estimate	Pr(> |t|)
Constant	−2.06	0.14	0.02	0.98
(*Internal economic variables*)				
House condition	0.06	0.45	0.02	0.71
Value of livestock	0.00	0.94	−0.01	0.15
Number of assets	−0.11	0.23	*−0.13*	0.01
Monthly total income	−0.13	0.13	−0.02	0.50
Forest cultivation area*	*0.01*	0.00	*−0.01*	0.00
Mixed garden area	0.00	0.37	0.00	0.68
(*Internal non-economic variables*)				
Education	0.02	0.66	−0.05	0.10
Family size	0.23	0.08	−0.09	0.33
Land tenure security perception	−0.07	0.48	*0.22*	0.00
Income from wife or children*	*−1.10*	0.01	*0.54*	0.03
Pruning species	*−1.01*	0.01	0.42	0.10
Gas stove	−0.70	0.15	−0.21	0.44
(*External variables*)				
Travel time to Forest*	*−0.81*	0.01	*0.48*	0.00
Government programs*	*−0.43*	0.03	*0.28*	0.01
Small fuelwood markets*	*1.35*	0.01	*−0.91*	0.00
Large fuelwood markets	*1.53*	0.01	−0.57	0.07
Log-Likelihood	−115		−243	
McFadden R^2	0.267		0.160	

* Variables significant ($P<0.05$) in both models

income from wives and children decreased the probability of collecting fuelwood from forests due to higher opportunity costs.

Similar to Group 1, the most important finding from Group 2 was the influence of non-economic characteristics of households and external conditions. Although the number of social assistance programs did not encourage the use of LPG as the only source of energy, it did seem to constrain fuelwood collection from the forest. The fuelwood markets regardless their sizes were the major factor driving fuelwood collection from forests. The households were less likely to collect fuelwood for domestic consumption from their garden areas only if there are fuelwood markets in the community.

Our results demonstrated the complexity of energy choices of households, and reinforce the principle of energy stacking. Rural households chose a variety of energy sources to meet their needs. These sources included the full spectrum of primitive to advanced fuels. Electricity is another energy source that we considered, but it was eliminated from the final set of explanatory variables due to the lack of variation among user groups, which demonstrates another dimension of energy choice complexity. Our sample included 36 households owning an electric rice cooker. Curiously, we found some fuelwood only users who used rice cookers (12), in addition to gas only (3) and mixed energy users (21).

3.3. Fuelwood demand for tobacco curing

Indonesia's Central Agency for Statistics (BPS) identified tobacco processing as one of the top five industries with energy as their main constraint (Tambunan, 2014). NTB province is one of five provinces where energy costs are the greatest challenge for industry development, although the BPS did not identify which energy sources are of particular concern (Tambunan, 2014). NTB's manufacturing sector is relatively small (only 5 percent of the total NTB economy), but two out of four sectors present in NTB require fuelwood as the primary energy source: the food and drink sector (including tobacco), and the inorganic chemicals sector (clay pottery, lime, and pumice powder made from crushed volcanic rocks) (REDI, 2013). A previous study in the area found that one village provides fuelwood for 16 different types of businesses consuming significant quantities of fuelwood, ranging from cracker makers to tofu factories (UNRAM, 2011). However, the largest consumer of fuelwood in Lombok is the tobacco industry, which requires flue-curing of tobacco leaves before the grade of their products and the price can be evaluated. Both predictable consistency and the quality of the energy supply is much more important for tobacco curing than for other types of fuelwood-based industries.

As mentioned earlier, Lombok is a major producer of tobacco, and about twenty tobacco companies are currently operating in Lombok (16–21 from 2009 to 2013; 20 as of 2013, BPS, 2013). The total tobacco growing area of NTB is estimated at more than 29,000 ha (6% of total cropland), producing 38,000 tons of cured tobacco (BPS, 2013). Three companies account for 63% of the total tobacco production in Lombok. PT. Export Leaf Indonesia (PT. ELI), a subsidiary of the world's second largest tobacco company, British American Tobacco group, accounts for 35% of the total area and production of tobacco in Lombok. The two other large companies, PT. DJARUM and PT. SADHANA, account for 14% each of total production (BPS NTB, 2011). Although the kerosene subsidy was primarily intended for household use (Budya and Arofat, 2011), tobacco farmers relied on kerosene as their main energy source for curing tobacco prior to 2007. The subsidy on kerosene was gradually reduced beginning in 2007 (IISD, 2014). Fig. 3 shows the changes in kerosene prices and use based on a series of surveys of PT. ELI contract farmers. Without the subsidy, the price of kerosene has increased ten-fold over the last ten years, and during that time kerosene became one of the most expensive sources of energy for tobacco curing.

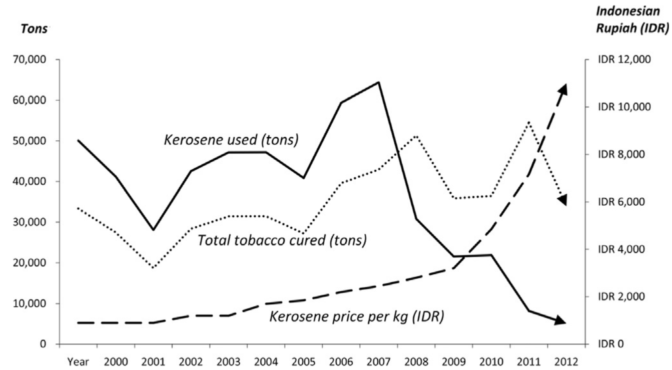

Fig. 3. Change in kerosene price and use by PT ELI contract farmers (Source: Sukardi and Hamidi, 2012).

Initially, coal was the primary alternative offered to tobacco farmers. High-grade coal can be a very efficient source of energy, if an adequate supply of oxygen can be ensured during combustion. In collaboration with the tobacco companies, the government offered a program providing financial support of up to Rp. 5 million (USD 500) per person, to convert furnaces for curing tobacco from kerosene to coal[6] (personal communication with Iskandar, PT. Djarum). However, the transition to coal largely failed due to a number of problems. Even with significant government support, coal furnaces are expensive and require special technical expertise to position and operate to ensure good air circulation (FFI, 2009). The sudden surge of demand for coal furnaces resulted in the use of poor quality equipment, and many famers lacked the skills to install and operate them properly. For complete combustion without a secondary fuel, coal also needs to be of a high grade (5300–6000 kcal/kg). Low quality coal yields about 4500 kcal/kg, which requires burning with a secondary fuel, often fuelwood, to minimize waste (FFI, 2009). Tobacco companies could not ensure the quality of coal supplied to tobacco farmers, and often tied the supply of coal to payment of company loans (FFI, 2009). This practice reduced financial risk to the company, but increased farmers' uncertainty about their fuel supply. To ensure consistency in the quality of cured tobacco, tobacco farmers turned to a more familiar energy source, fuelwood, which does not require special equipment or skills, and can be supplied economically and consistently.

Tobacco farmers often use fuelwood in combination with other energy sources. A previous survey showed that there are 25 different combinations of energy mixing commonly used for tobacco curing, with 12 options involving some use of fuelwood (Sukardi and Hamidi, 2012). Table 4 shows the unit cost per one kg of tobacco cured and the production of cured tobacco per each fuel type in 2012 for PT. ELI contract farmers. Although a variety of nut shells (e.g. pecan, candlenut, and cashews) can be used economically, their supply is limited. Fuelwood accounted for 67% of total tobacco cured. Among the nine fuel sources, fuelwood is revealed as the most cost-effective, and with the most reliable and predictable supply.

Several alternatives are being developed by different tobacco companies. Because of its stated commitment to green development and Corporate Social Responsibility principles, PT. ELI has decided to completely eliminate the use of fuelwood for tobacco curing among their contract farmers by 2015. Company leadership

[6] The government and the tobacco companies reached agreement on establishing the DBHCHT (Dana Pembagi Hasil Cukai Hasil Tembakau), which offered financial support to farmers for converting kilns from kerosene to briquette with Rp. 5 million per person.

Table 4
Cured tobacco per fuel type in 2012.
Source: FFI (2009) and PT ELI (2012).

Type of fuels	Cost of fuels[a] (Rp per kg)	Tobacco Cured (kg)	Percent (%)
Kerosene	9025	218,113	1.69
Diesel fuel	9139	225,543	1.75
Fuelwood	4368	8,623,861	67.05
Coal	5120	439,176	3.41
Coal briquette	7590	313,581	2.44
Oil Palm shell	4800	1,194,589	9.29
LPG	7200	29,748	0.23
Nut shell	3630	1,816,386	14.12
Total		12,861,000	100.00

[a] Per cured tobacco.

is encouraging the use of other biomass sources, such as palm oil kernels and candlenut shells. The company is also aware of the fact that fuelwood demand greatly exceeds available supply, and is concerned about losing their competitive edge to those in more timber-rich regions. In addition, fuelwood burning can affect the quality of tobacco by introducing plastics, which are hard to detect, from the ties of fuelwood bundles (PT. ELI, 2012). PT. DJARUM is also encouraging their farmers to use alternative biomass sources (Iskandar, PT. Djarum, personal communication). Conversely, PT. SADHANA is encouraging use of fuelwood from sustainable sources, and is promoting plantation of fast-growing tree species on private or communal lands, and in industrial plantation forests on State forest lands, to supply fuelwood for their farmers (Badrun, PT. SADHANA, personal communication).

4. Discussion

We focused on answering three questions in this paper. First, we found that the presumption of rural household energy use as a driver of deforestation and forest degradation has not been correct. For example, most of the households we surveyed reported that they use 0.04 m^3 of fuelwood per day (14 m^3 per year). They use pruned branches, dead wood and other woody biomass, which can be sufficiently and sustainably collected from their cultivation areas. This confirms the results of previous studies that fuelwood for domestic uses often comes from lots and woodlands outside of forests (Cooke et al., 2008; Hiemstra-van der Horst and Hovorka, 2009), and mostly consists of dead matter, which has little impact on forest conditions (Morton, 2007). Our results also confirm the earlier finding by Andadari et al. (2014) in central Java that the energy mega-project did little to reduce fuelwood consumption and created more opportunities for energy stacking.

Second, non-economic characteristics of households and external conditions strongly influenced household fuel choices and the sources of fuelwood.

Fuelwood collection activities for domestic consumption may be part of activities connected to commercial fuelwood production. Small-scale fuelwood markets would provide added incentives to collect more fuelwood than the amount needed for household consumption. Large-scale fuelwood extraction is often associated with contracting with outsiders through middlemen who bring technologies that accelerate fuelwood and timber collection, including chain saws, mobile mills, and trucks. This activity is directly linked to household economy and provides more opportunities to collect fuelwood for domestic consumption while providing labor during harvest. The influence of these external factors, such as the market environment, has been neglected in previous academic discussion of household energy choices.

Third, we found that fuelwood demand for processing agricultural products has significant impacts on forest conditions. According to recent field measurements (Bae et al., 2014), the average growing stock of biomass in the Rinjani Barat Forest Management Unit is 137.1 m^3/ha for primary forest, and 130.3 m^3/ha for secondary forest. To cure one kilogram of tobacco, 5.2 kg ($\approx$ 0.008 m^3) of fuelwood is required (PT. ELI, 2012). If we extrapolate the rate of fuelwood use from an earlier survey of PT. ELI contract farmers, we can assume 67% of the total (38,000 tons of tobacco produced in 2012) is being cured with fuelwood. This would require approximately 204,000 m^3 of wood per year, which is equivalent to clearcutting approximately 1500 ha of forest per year (1486 ha of primary forest, or 1563 ha of secondary forest). To ensure sustainable harvest, we would need to spread the harvest to at least 7,628 ha (of secondary forests)[7], which would mean that more than 10 % of the total secondary forest area in Lombok would need to be dedicated to tobacco-curing alone.[8]

The energy options being explored by tobacco companies all seem to be viable alternatives to the current challenge of securing consistent, quality, and economical energy sources, but what is curiously missing here is the voice of the government. Compared to the national kerosene subsidy and the massive campaign to promote LPG use at the household level, the government has offered no cohesive strategy for addressing the energy needs for processing agricultural products like tobacco and palm sugar, as well as for other small businesses producing processed foods (e.g. tofu, tempeh, and crackers), pottery and building materials (e.g., brick and tile). Absent the development of a coordinated, overarching government policy, one or more companies deciding to limit the use of fuelwood among their contract farmers can actually result in perverse incentives for others to exploit more forests.

5. Conclusions and policy implications

The central thesis of the energy ladder model is a unidirectional transition based on economic development. Although the energy ladder model has been largely discredited, its philosophical base, modernization theory, still prevails in many *laissez-faire* policies for developing countries to simply follow in the footsteps of developed countries (Sunderlin et al., 2005). Our results demonstrate how such policies, based upon this simplistic energy ladder theory and implicit expectation of spontaneous forest recovery with economic development, can undermine broader policy objectives and lead to worsening forest conditions in rural Indonesia. The elimination of the kerosene subsidy was certainly successful in reducing kerosene demand. However, the program did little to reduce rural household demand for fuelwood, and actually resulted in a dramatic increase in fuelwood demand for processing agricultural products. Our analysis demonstrates how household energy choices and the collection of fuelwood are likely affected by non-economic characteristics and external factors, such as opportunities to sell fuelwood. We argue that household fuelwood use may therefore be a symptom, rather than a driver, of deforestation and forest degradation.

Our findings can inform policies in several ways: First, the lack of understanding of the local context and the energy stacking process can undermine the broader policy objectives of energy subsidy reform and the LPG program. Households in rural Indonesia are economically rational decision-makers (Pattanayak et al., 2004). They choose the most easily accessible, economically affordable, and culturally acceptable energy source within the

[7] 27.6 m^3/ha/yr, average of Mean Annual Increment of Acacia, Sengon, Calliandra, Rubberwood, Mangium and Lamtoro. Source: Nurhayati et al. (2006).

[8] Total forest area in Lombok is about 118,000 ha with 67,000 ha of secondary forest as of 2010 (Bae et al. 2014).

local institutional and physical contexts (Foell et al., 2011). Thus policy interventions to promote new energy sources or technologies must include not only the institutional changes to secure future supply and affordability, but also educational programs to inform people of the benefits to individual households (e.g., health concerns from inefficient burning) of adopting new energy sources or devices.

Second, policy interventions to encourage energy transition of households do not necessarily improve forest conditions. Fuelwood consumption of individual households for everyday cooking is not a significant contributor of deforestation and forest degradation. An explicit recognition of this aspect can inform future policies with clear expectations of the policy outcomes.

Third, policies to improve forest conditions should focus more on addressing the market environment of forest-margin communities. We found that fuelwood markets in any size can affect household energy choices and the sources of fuelwood. While small-scale operations by landless poor with limited equipment pose little threats to forest conditions, commercially organized large-scale markets are driving significant forest degradation and deforestation. In order to address this issue, policies must address both supply and demand sides of fuelwood consumption. Two policy options can be considered for the supply side: developing measures to limit harvest rates to sustainable levels and developing plantations to lessen pressure on ‘natural’ forests (Hofstad et al., 2009). Thus, improving forest management and planning would be important, as well as promoting active plantation in previously degraded lands with fast growing biomass species.

Fourth, law enforcement prohibiting illegal forest use would also make fuelwood less available and accessible to households by increasing the opportunities cost of fuelwood collection. Our results show that participants of government-led programs may not change their energy choice, but that programs may affect where they collect fuelwood, as does the income from women and children. Increasing government presence and expansion of economic opportunities, especially for women, could promote more sustainable fuelwood collection.

Fifth, to address the demand side, policies and programs to improve forest conditions should provide energy alternatives to small industries that are the larger consumers of fuelwood. Although promoting alternative energy sources and improving the process of drying and burning of biomass would be a clear way to reduce the demand for fuelwood, it is not a simple question of distributing different burners. Micro- and small businesses lack managerial and technical capacities and have limited access to financial resources. As noted earlier, most micro- and small businesses in Indonesia are unregistered and largely operate within the informal sector (Tambunan, 2014). Policy interventions should include removing barriers, and providing incentives for small businesses to be recognized as formal contributors to the overall economy. Incentives can include increasing access to financial and technical assistance to enhance access and efficiency in energy use, and improving infrastructure and public transportation facilities in rural areas. The focus should be on building the capacities of these businesses for adopting best practices of energy alternatives.

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