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DISCUSSION BRIEF

Investigating ecology and poverty dimensions of biomass use and energy access: methodological issues

Summary

Energy access, ecosystems health and poverty are deeply linked in areas where there is a heavy reliance on traditional biomass fuels. Attempts to improve access to modern energy can benefit from exploring these links and interactions, particularly effects on ecosystem services on which communities rely.

An ecosystems services approach offers a useful alternative to socio-economic or techno-economic approaches to the study of linkages between energy access and poverty. It can be used to evaluate different resource management and energy access alternatives, but requires an interdisciplinary approach encompassing a variety of methods and tools.

This discussion brief gives a brief overview of the basics of, and methodological issues relating to, three research methods that have been successfully applied in this area:

- Demand-side surveys
- Supply and value chain analysis
- Economic modelling of consumer choice

More than 2.6 billion people worldwide and 80% of households in sub-Saharan Africa depend on traditional biomass (fuelwood, charcoal, agricultural residues) to meet their daily energy needs (IEA/WEO 2014). Many small-scale enterprises (e.g. brick-making, food processing) and service institutions (e.g. schools, health clinics) also rely on traditional biomass energy. However, lack of access to modern energy services impacts health and well-being, contributing to a deepening cycle of poverty and human underdevelopment (Bhattacharya 2013).

Energy access and biomass use have generally been treated as techno-economic or socio-economic issues, with the focus on the affordability and availability of modern fuels and energy applications or systems. From this perspective, scaling up demand and supply of modern alternatives directly addresses the relationship between poverty and energy access (Pachauri et al. 2013). It is assumed that increased uptake of modern energy services, in turn, reduces the health and environmental impacts associated with inefficient energy sources (Bhattacharyya 2013).

An alternative lens to study the interface between energy access and poverty reduction incorporates ecological dimensions, including how different energy and biomass use options interact with ecosystem services on which rural people rely. In this context, better management of natural resources is a way to enhance human welfare and reduce poverty. The resulting higher income levels and greater availability of resources then facilitate access to modern energy services (Ganz et al. 2012). Such approaches have the advantage of considering both agricultural and forest-based biomass fuels and feedstocks, alongside water and other resources, in a common framework.

The ecosystems services approach has been proposed as a way to analyse bioenergy investments that can capture both positive and negative links to human well-being and poverty reduction (Gasparatos et al. 2011). Taking the case of liquid biofuels, investments in these can increase access to a cleaner and more modern form of household energy, but biofuel feedstock cultivation in rural areas where communities rely on subsistence agriculture and local resources adds dimensions of land competition to the energy-poverty-ecology equation (Harvey and Pilgrim 2011). Since biofuels may be used locally as well as being traded nationally or internationally, methodological choices in defining system boundaries become more significant, as is discussed further below in relation to supply chains.

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Charcoaling freshly cut wood in the forests of Center Region, Cameroon

In rural areas where access to modern energy is currently limited, methodological approaches that link measures of ecology and poverty can facilitate detailed comparisons and assessments across the complex socio-ecological interface between local people and their natural environment. Analogous methods have been used in evaluating agro-ecosystems where livestock and crop residues are significant for economic welfare (Valbuena et al. 2014). At the same time, the physical and technical principles of biomass assessment must be incorporated (Rosillo-Calle et al. 2012).

Applying an ecosystems services approach to study this topic, and to evaluate different resource management and energy access alternatives, requires interdisciplinary work encompassing different methods and tools. Some of the key issues to consider, along with a selection of useful study methods, are discussed below. In particular, we consider surveys, supply and value chain analysis, and demand-side modeling of consumer choice. Brief mention is made of other complementary or supplementary methods.

The examples and approaches presented here emphasize fuelwood and wood-based charcoal, since these are the main traditional energy sources in sub-Saharan Africa. However, the same approaches can be applied to other fuels and systems. The case of ethanol for cooking is also included here so as to consider the role of liquid biofuels. Biogas is not included, since the requirements and conditions for its production and use are quite different.

Some issues related to an ecosystem services approach

In poor rural areas, energy services constitute a direct spatial interface between ecosystem health and human welfare. This is primarily because the fuel is generally sourced from the local environment; however, production of charcoal for sale in urban and peri-urban areas may also represent a big cash income stream for the same rural communities. Furthermore, they may be dependent on subsistence farming, including slash-and-burn agriculture, which together with fuel use and production impacts biodiversity and contributes to greenhouse gas (GHG) emissions from land-use change (Palm et al. 2013). This in turn affects local ecosystem services, including by exacerbating biomass scarcity, deepening poverty and further reducing the prospects for improving energy access (Johnson and Jumbe 2013).

The impacts of fuelwood and charcoal use are challenging to monitor, since they tend to contribute primarily to land degradation rather than deforestation, which is hard to measure through the remote sensing techniques that are used to track deforestation (Geist and Lambin 2002).

In order to identify the most suitable sets of strategies or interventions to improve energy access and reduce poverty, both direct and indirect drivers should be assessed. Furthermore, it is important to consider impacts at multiple levels; inefficient biomass fuel use has local, regional and global impacts. The contribution of charcoal production to GHG emissions and global climate change has been well characterized using lifecycle analysis (LCA) approaches (Kituyi 2004). Analysis of alternative modes of energy provision should therefore adopt a similar approach, placing special emphasis on the ecosystem services that are impacted through reliance on biomass energy, and changes that a switch to cleaner alternatives could bring about. In this respect it is important to consider the full range of ecosystem services, including provisioning, regulating, supporting and cultural services (Figure 1).

As an illustration, most of the direct local ecological impacts of the urban and peri-urban use of traded charcoal would be felt in the rural areas where the charcoal was produced, rather than the urban areas themselves. For example, if too much wood is extracted for charcoal production, then fuelwood supply for nearby communities (a *provisioning* ecosystem service) would be negatively affected. However, both groups could be affected by resulting longer-term changes in the *regulating* services

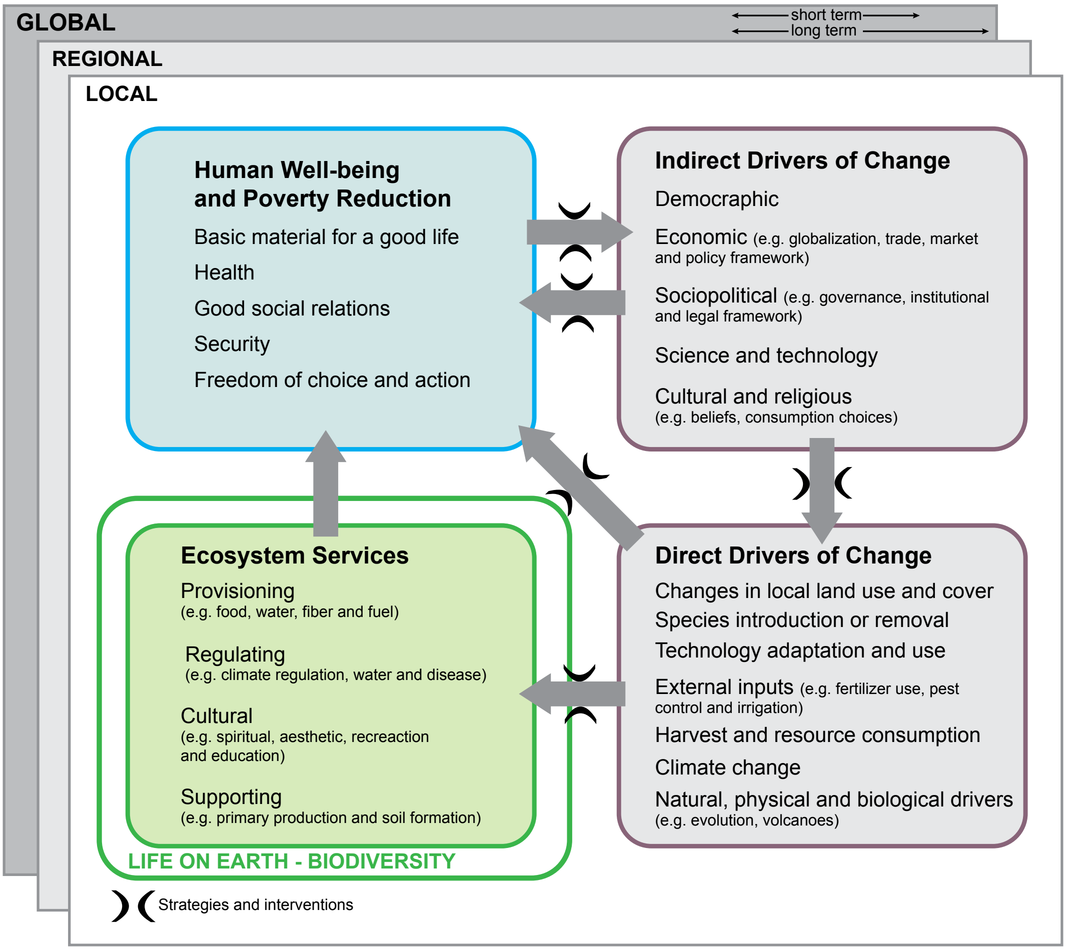

Figure 1: Conceptual framework of interactions between biodiversity, ecosystem services, human well-being, and drivers of change

Source: Based on Millennium Ecosystem Assessment (2005).

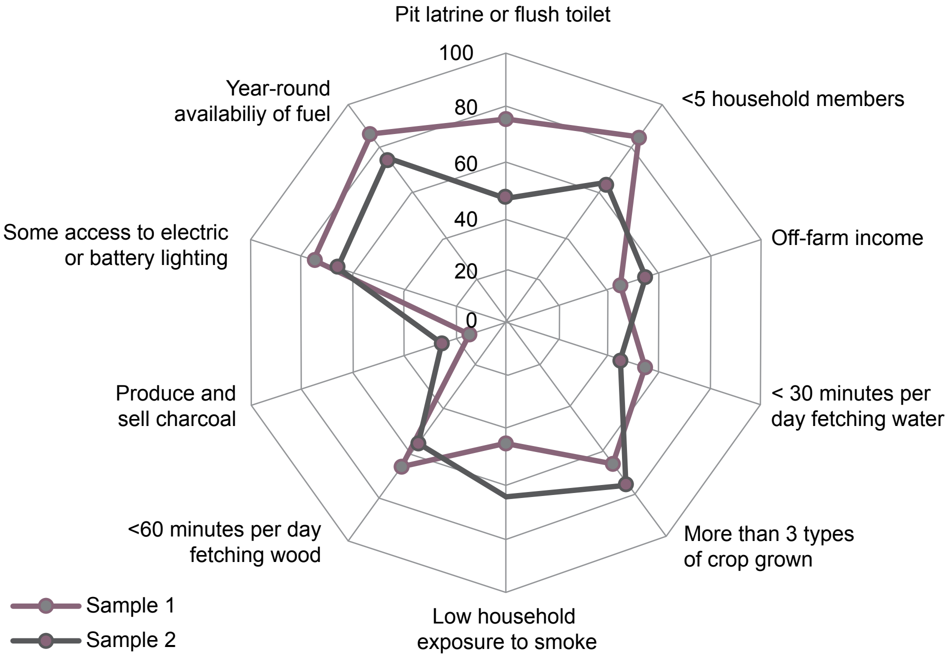

Figure 2: Comparison of hypothetical samples for different physical, socio-economic or demographic metrics relevant to a rural assessment of poverty and energy access, using an ecosystem services approach (value = % of respondents)

experienced on a regional scale (e.g. rainfall patterns) as well as global impacts from climate change.

The ecosystem services approach is differerent in important ways to energy-climate-development assessments, where specific targets or criteria are often evaluated. In particular, it allows for assessment of the interactions and dynamics across the physical-economic landscape (Gasparatos et al. 2011). Coupled socio-ecological systems can thereby be studied; i.e. resource managers and users are analysed within the local ecological context.

Applying the ecosystem services approach requires development of suitable measures and indicators to address the relationship between poverty and ecological impacts. For example, since informal economic activity normally dominates in rural areas of developing countries, income, wages and other monetary measures are not particularly useful in distinguishing different levels of poverty. Instead, the relationship between energy access and poverty needs to be coupled with an investigation of how different ecosystems services are managed, used and valued locally (Bailis et al. 2012). Surveys can then be designed to capture relevant data.

Because there is considerable heterogeneity in how resources are managed, even between areas with similar physical and socio-economic characteristics, surveys should also capture detailed data on the use of biomass and other resources. They can then be used to determine the value that users place on ecosystem services under different physical and economic conditions.

Some examples of different metrics that could be useful in an ecosystem services assessment on energy access, biomass use and poverty are shown in Figure 2. The survey methods needed to gather such data are discussed further below.

Demand-side surveys

Surveys are a useful way of gathering detailed data on the type, quantity, quality, management and end-uses of biomass (for energy and others) by households or enterprises. Among other things, data gathered in such demand-side surveys can be used to assess not only current choices of stove and fuel but also what may be preferred and/or feasible in the future.

The type of survey and its design depend on the research questions or phenomena being studied, and on the time and resources available. Often multiple techniques are applied within the same study in order to gather complementary data types that can be analysed together.

The study design that informs the survey structure can be based on cross-sectional data, examining a set of variables for a chosen population at one point in time, and longitudinal data, gathered through repeated observations of the same variables over longer periods. A cross-sectional survey could, for example, be used to take a snapshot of energy-use patterns in a community and assess how they vary with socio-economic status/poverty levels. However, it would not show why those variations occur. A longitudinal survey, on the other hand, would be more appropriate to reveal causal relationships, as the data would allow comparison of trends in different variables as well as changes following external triggers (e.g. implementation of a new energy access policy).

Surveys often use questionnaires, structured interviews, or both, and can gather both quantitative and qualitative data. Additional methods that draw on a social context (e.g. focus group discussions or structured meetings) might be used in a supplementary or complementary fashion or as a step in survey design to help better define the scope.

Household surveys offer a relatively simple means of collecting a wide range of standardized information that can be statistically analysed and used to draw key inferences on a specific population group. They also have the advantage of being able to gather—using a single instrument—physical, social and economic information, including on attitudes, beliefs and past behaviour; this capability is especially relevant and effective for ecology/poverty approaches to energy access and biomass use.

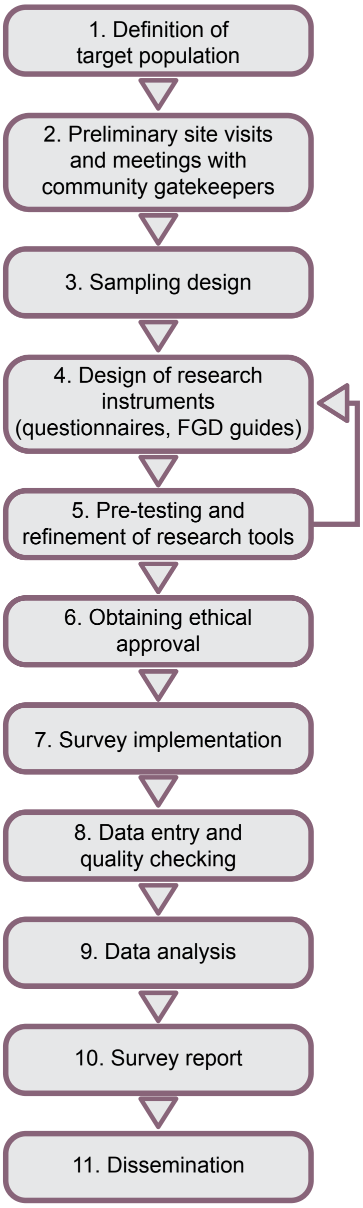

Figure 3: Elements in the design and implementation of a household survey

Properly designing and implementing household surveys can be time-consuming, with many steps involved (see Figure 3). Other challenges and considerations include:

- Household surveys depend on respondents' motivation and ability to respond, and to do so truthfully and accurately.
- Structured surveys, particularly those with close-ended questions, may have low validity when researching cause and effect, as relevant variables may not have been identified and included.
- Even with careful sample design, respondents are to some extent self-selected, since responding should be voluntary as a matter of principle (pressure to respond inevitably affects the validity of the responses).
- Various biases are introduced in interactions between interviewer and interviewee, and these can vary over time and with different interviewers.
- Achieving a statistically valid random sample may be difficult due to issues such as households with off-farm work opportunities being deserted when interviews are carried out, difficulties in accessing households far from main roads, and lack of a good database from which to draw a random sample. Finding households in areas without named streets can be nearly impossible.
- A large population is needed in order to detect differences in the population groups studied (especially in cross-sectional surveys).

The survey process must be rigorous to anticipate and account for, where feasible, these potential difficulties and biases.

Alongside more structured surveys, there are also more *participatory survey methods* such as participatory rural appraisal (PRA), community-based participatory research, and participatory geographical information systems (GIS) research. Such methods are not only useful for studying particular phenomena, but can also be a way to affect outcomes, induce learning, and build local capacity. Like focus group discussion, they can also be used prior to designing a questionnaire to ensure that the correct assumptions are being made, and the correct questions asked.

Supply chain and value chain analysis

Analysing the supply side for biomass resources, and identifying potential interventions, requires knowledge of the *supply chain* and *value chain*. These chains can be short or long, with many stages and actors.

Figure 4 shows a generic supply chain for biomass energy. Between feedstock growth and end use there can be pre-and post-processing of the biomass (i.e. before or after conversion), along with transport and trade. Solid biomass is bulky and has a low energy density compared to fossil fuels, making logistics and transportation important in both economic and environmental terms. Logistics, transport and handling for liquid biofuels (bioethanol, vegetable oils) are easier in some respects but differ in terms of other processing requirements. The extent of biomass/energy loss along the supply chain should also be considered. The value chain is similar to the supply chain, but is concerned with the economic value added or lost at the different stages.

The charcoal supply and value chains are particularly interesting in sub-Saharan Africa, due to their great significance in economic and environmental terms. Wood-based charcoal is

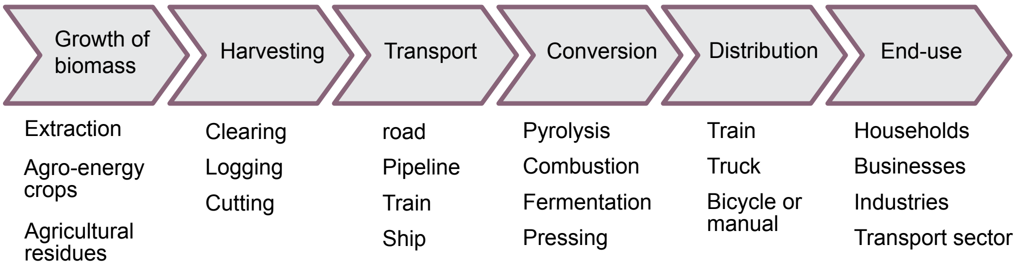

Figure 4: A generic supply chain for biomass energy

produced mainly in earth kilns, a highly inefficient process in terms of energy loss. (Some pioneering efforts have been made to establish more efficient production of charcoal briquettes and industrial pyrolysis platforms.) The energy density of charcoal is nearly twice that of fuelwood; this, along with the availability of "free" raw material, are key reasons why it has become the major fuel for peri-urban and urban areas of sub-Saharan Africa.

The charcoal value chain is a significant source of livelihoods and a means of off-farm income in rural areas. Actors in the supply chain whose livelihoods are supported by charcoal include producers, transporters, wholesalers, retailers and eventually the final consumers that are normally located in urban or peri-urban areas. However, the charcoal sector is also responsible for local ecosystem damage, negative health impacts and greenhouse gas (GHG) emissions (Zulu and Richardson 2013), with their associated costs

Photo Travis Lupick / IPS / Flickr

Loading charcoal ready for transporation to urban markets

Impacts and losses occur all along the charcoal supply chain but can be heavily concentrated in the harvesting and conversion stages (see Figure 5). From a biomass resource perspective, the critical issues lie in the conditions of growing and harvesting. Unsustainable harvesting for charcoal production leads to land degradation (it often includes felling live trees), damage to soils and/or loss of ecosystem productivity (Chidumayo and Gumbo 2013). A number of other characteristics of the charcoal sector make it problematic in ecological, social and economic terms:

- Charcoal is a commercial commodity, yet its production is illegal and/or unregulated in many countries (including most African countries).
- Enforcement of charcoal production bans is complicated by rampant corruption.

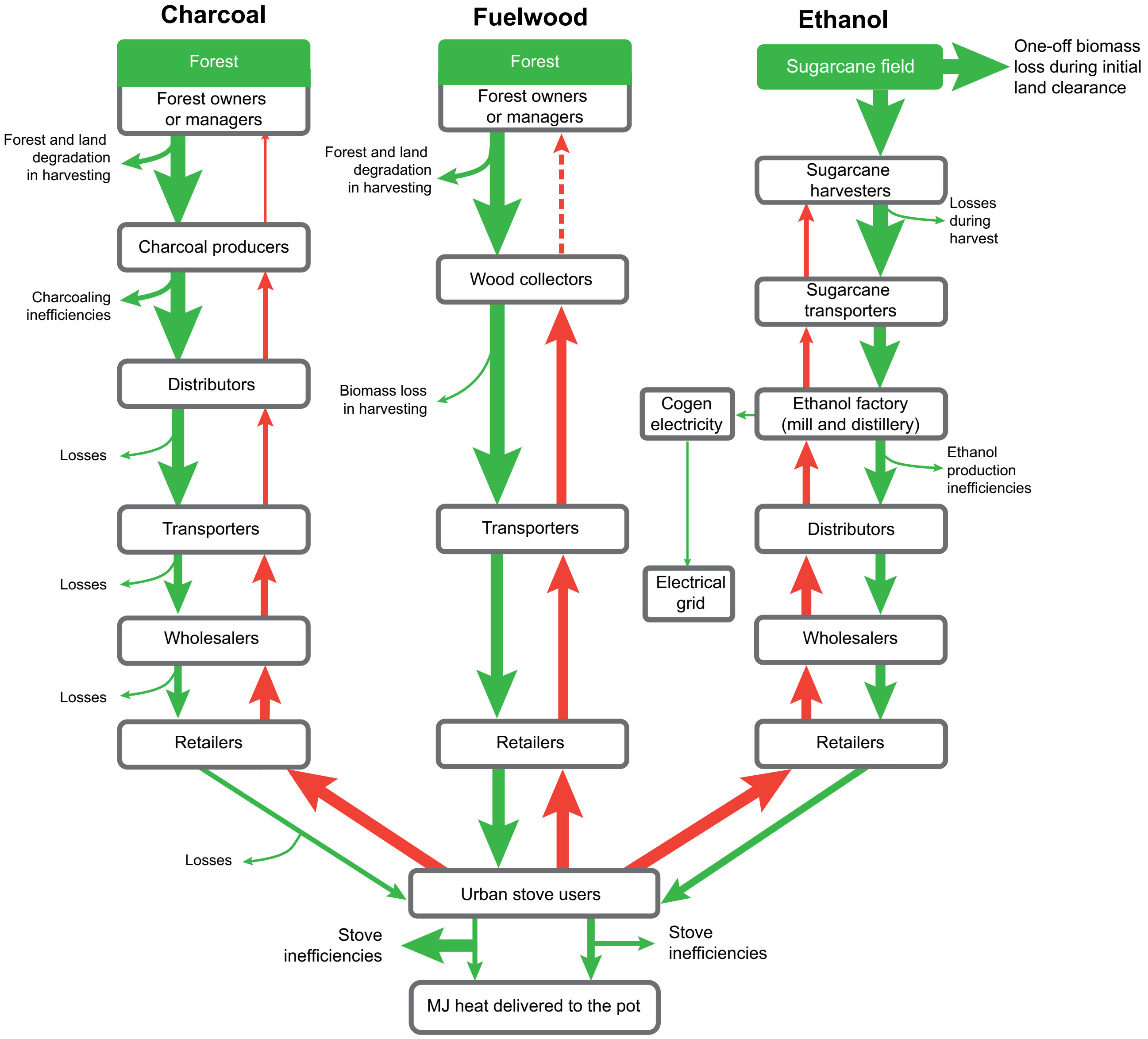

Figure 5: Indicative comparison of land-use impacts and value chains for charcoal, wood and ethanol for cooking

Green arrows show energy flows; red arrows show financial flows. Arrow thickness is roughly proportional.

- Conversion technologies are inefficient since there are few incentives to invest in higher-quality processes, especially since operations may have to be moved to avoid detection by authorities.
- Charcoal production is often perceived as a business for the poor that is "dirty" and unattractive.
- Access to raw material is considered free, even though its use may impose direct environmental and social costs in the nearby communities.
- The charcoal trade has an oligopolistic structure: instead of equitable revenue-sharing along the entire value chain, traders keep the bulk of the revenues (Shively et al. 2010).
- Actors in the charcoal trade are reluctant to formalize their operations, as this would be likely to result in direct losses through taxation (or fines) and reduced access to raw materials.
- Charcoal production is sometimes linked to agricultural expansion, which prevents tree regrowth.

An important step in supply and value chain analysis is to compare the returns at different points in the respective chains with the land-use impacts. Policies and interventions can then be aimed at aligning returns with lower impacts.

Figure 5 illustrates a way of visualizing supply and value chains, along with the distribution of losses and returns at the different stages. It shows a hypothetical chain linking rural charcoal production to urban or peri-urban markets and use for cooking. Fuelwood and bioethanol supply and value chains are also included for comparison. The green arrows indicate the scale of possible energy losses through the supply chains, relative to the energy on the initial forested land. The red arrows show possible distribution of revenues along the value chains. Note that these are indicative only, and not based on empirical data.

Improvements in the sustainability of charcoal supply chains require more transparency and accountability in terms of the roles, activities, effectiveness, and inter-relations among the different stakeholders. Gaps in policies and regulations must be addressed at key steps in the supply chain. Both informal and formal institutions must be considered, particularly at the stage of extraction, where issues of land tenure and access to resources must be resolved. Studies have suggested that the informal, illicit nature of charcoal production also contributes to the inequalities observed in the value chain (Zulu and Richardson 2013). Formalization of the charcoal trade can offer sustainability benefits, particularly where governance responsibility can be devolved to local levels, encompassing monitoring mechanisms and tax incentives (Schure et al. 2013).

Economic modeling of consumer choice

The uptake of different fuels or technologies depends on consumer demand. Various methods, including qualitative surveys, can be used to gather data on consumer demand for modern energy. Application of models can help in transforming the information in ways that can be statistically analysed and used to predict consumers' behaviour. These findings can be useful in understanding the demand side of the market better and thus to inform stove design and selection as well as policy design and marketing.


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Ethanol cookstoves (such as the CleanCook, shown here being used in Guatemala) are a cleaner-burning but often more expensive alternative to charcoal and wood stoves.

One approach for economic modelling is *discrete choice analysis* (McFadden 1981), which has been applied in a study of cookstove choices in Ethiopia, Tanzania and Mozambique (Takama et al. 2011). Applying a discrete choice model represents a major step forward in understanding consumer preferences as it permits analysis of trade-offs between specific possible attributes of a product, particularly between monetized and non-monetized attributes. The theoretical model is based on random utility theory, and uses statistical tools and experimental survey techniques to estimate the relationship between attributes of different alternatives, which are modelled as discrete choices rather than being based on continuous levels of demand. Application of the approach and the model are discussed further below.

Selection of attributes and alternatives

To understand consumers' current and likely future choices regarding stoves (and associated fuels), there are several reasons to look not at the stoves per se but at its different functions or economic and non-economic attributes (such as price or smokiness); how consumers are willing to trade off between them; and how this affects their overall assessment of the value of purchasing a particular stove and thus their ultimate choice.

If price were the only attribute considered in a choice between a firewood stove and a more expensive ethanol stove, we would naturally expect the consumer to choose the firewood stove. However, if the analysis also took into account smoke level, for example, the final choice would involve a trade-off between price and smokiness, and some consumers might be willing to pay more for a cleaner-burning ethanol stove. This is because consumers have different beliefs and attitudes about these stoves and their attributes, translating in economic terms to "utility".

The researcher must identify and refine the relevant alternatives and attributes, and then determine the ranges to be tested. Having done this, the researcher can design a survey to explore users' preferences.

Preference surveys, with a choice experiment

Surveys on consumer preferences can take two main forms: revealed preference (RP) surveys and stated preference (SP) surveys. In a revealed preference survey, the researcher studies the choices that users have already made (which directly "reveal" their preferences). In contrast, in an SP survey the researcher asks potential consumers to choose between hypothetical alternatives with stated attributes. The researcher

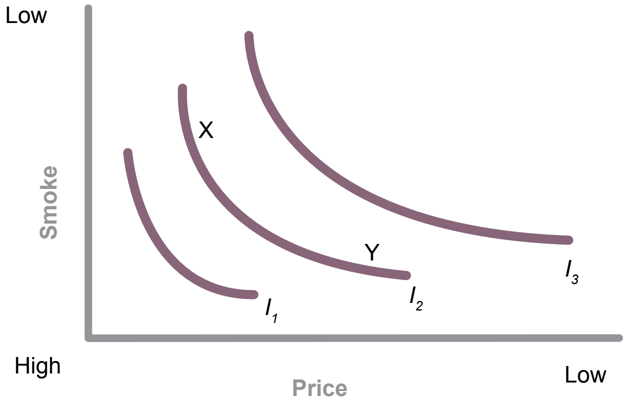

Figure 6: Hypothetical indifference curves for choice of cooking stove based on price and smokiness

asks multiple questions on different combinations of attributes at given levels (e.g. a smoky and unsafe stove that costs less or a safe and smokeless stove that is expensive).

SP is often used for discrete choice analysis as it is more efficient (in terms of research effort) than a conventional RP survey, which only yields one observation from each consumer. Moreover, RP gives a limited variety of data due to technological constraints and competition between similar products. For example, a stove producer cannot offer stoves that are much more expensive than similar products due to market competition. For the same reason, a consumer will not find a good quality (e.g. low smoke level) stove at a cheaper price. In contrast, using an SP survey, the researcher is free to choose any combination of attributes that could be used as the basis of future stove design (Takama et al. 2012). It then becomes the responsibility of the model designer to choose alternatives that are considered technically feasible in general terms.

Choice analysis

“Indifference curves” in economic theory describe the choices about which a consumer is “indifferent” in the sense that he or she expects to receive the same satisfaction or utility from either alternative. These can be calculated based on preference survey data. Figure 6 shows indifference curves for three hypothetical consumers (I_1, I_2, I_3) related to different trade-offs between price and smokiness. Points X and Y show two different price and smokiness combinations from which consumer I_2.receives the same satisfaction or utility. In this case, point X represents an option with lower smoke but higher price, compared to point Y. The trade-off between attributes forms the theoretical basis for the demand assessment.

Discrete choice analysis mathematically translates the utility values revealed in the survey into a probability value for consumers choosing specific alternatives – and thus their expected market shares – which is expressed through the logit model. A basic logit formulation for the case of three alternatives (A, B, C) is as follows:

$$P(A) = \frac{\exp(U^A)}{\exp(U^A) + \exp(U^B) + \exp(U^C)}$$

where U^x is the consumer utility for option x and $P(A)$ is the probability of choosing alternative A, which is equivalent to its expected market share. A fundamental assumption in practical terms is that if purchasing an ethanol stove brings higher utility than a firewood stove, i.e. $U(\text{ethanol}) – U(\text{firewood}) > 0$, a consumer will purchase the ethanol stove.

It should also be noted that the theoretical constructs and methods discussed here are general and could be applied to any problem in which a collection of attributes can be used to describe alternatives. It could be applied, for example, to certain choices in the charcoal supply chain discussed previously, such as attributes for resources and conversion technologies. However, in other fields, application of this approach to final consumer demand is more common and relevant and thus we have focused on the fuel and stove choice example here.

Concluding comments

In facilitating integration of biomass resource assessment alongside physical and economic variables, the ecology/poverty approach is particularly useful for studying energy access and biomass use among the rural poor, who are so reliant on natural resources. This review provides only a brief introduction to some of the key issues regarding assessment of the ecology/poverty dimensions of energy access and biomass resource use, and the analytical methods that can be employed.

A few points can be noted with respect to these methods and their application. First, survey methods and tools such as questionnaires are important for analysing energy access in relation to ecosystem health and poverty reduction; their design and implementation, however, require considerable time and effort, and complementary methods are needed to capture the local context and reduce bias. Second, value chain analysis combined with analysis of the impacts along the physical supply chain can provide a useful basis for designing policies and institutions to improve sustainability in production and use of different biomass fuels, particularly charcoal. Finally, using survey data and economic demand models makes it possible to compare existing and future options in a highly structured manner, but requires careful specification before the survey process is initiated.

Further reading

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