Jane Carter Ingram · Fabrice DeClerck
Cristina Rumbaitis del Rio *Editors*

# Integrating Ecology and Poverty Reduction

## Ecological Dimensions

Foreword by Professor Jeffrey D. Sachs,
Director of the Earth Institute

Springer

# Contents

# Chapter 18
# Ecological Sustainability of Woodfuel as an Energy Source in Rural Communities

**Rob Bailis, Jeff L. Chatellier, and Adrian Ghilardi**

## Introduction

### *Overview of Woodfuel Use in Developing Countries*

Between one-third and one-half of the world's population rely on wood and other biomass fuels[1] to meet their energy needs. Table 18.1 shows an estimate of the number of people relying on biomass fuels in 2004 from the International Energy Agency (IEA 2006). The use of wood as a household fuel is overwhelmingly concentrated in less developed countries where alternative fuels like natural gas, kerosene, liquefied petroleum gas (LPG), and electricity are inaccessible. Heavy reliance on woodfuel is associated with a range of social and environmental challenges including health problems resulting from exposure to indoor air pollution (IAP) and environmental change, which ranges from local degradation of forests and woodlands to large-scale changes in land cover and greenhouse gas emissions. In addition, supplying woodfuels requires high labor inputs, which, in many places, is often a burden for women and small children.

The problems associated with biomass use rarely arise as a result of wood consumption alone; rather, they are the result of complex relationships between wood

[1] The terminology used for fuels derived from woody biomass deserves some explanation. In this discussion, we use the term *woodfuel* to encompass minimally processed firewood, as well as charcoal and other solid fuels derived from lingo-cellulosic materials, such as sawdust or wood-waste briquettes (see FAO 2000, for a more detailed explanation). Non-woody forms of biomass, such as crop residues and dried dung are also used for traditional energy applications, and are associated with similar consequences.

R. Bailis (✉)
Yale School of Forestry and Environmental Studies, 195 Prospect Street,
New Haven, CT, USA
e-mail: robert.bailis@yale.edu

J.C. Ingram et al. (eds.), *Integrating Ecology and Poverty Reduction: Ecological Dimensions*, DOI 10.1007/978-1-4419-0633-5_18,

**Table 18.1** Estimates of the number of people relying on biomass resources as their primary fuel for cooking in 2004 (International Energy Agency 2006b)

| | Total population (millions) | | Rural (millions) | | Urban (millions) | |
|---|---|---|---|---|---|---|
| | % | Total | % | Total | % | Total |
| Sub-Saharan Africa | 76 | 575 | 93 | 413 | 58 | 162 |
| North Africa | 3 | 4 | 6 | 4 | 0.2 | 0.2 |
| India | 69 | 740 | 87 | 663 | 25 | 77 |
| China | 37 | 480 | 55 | 428 | 10 | 52 |
| Indonesia | 72 | 156 | 95 | 110 | 45 | 46 |
| Rest of Asia | 65 | 489 | 93 | 455 | 35 | 92 |
| Brazil | 13 | 23 | 53 | 16 | 5 | 8 |
| Rest of Latin | 23 | 60 | 62 | 59 | 9 | 25 |
| Total | 52 | 2,528 | 83 | 2,147 | 23 | 461 |

*Source*: IEA analysis based on latest available national census and survey data

consumers, the environment in which they live and the larger political economy. Therefore, understanding the environmental challenges associated with woodfuel consumption is only possible by considering the social, political, economic, and environmental context in which they arise. This chapter focuses primarily on the challenges to ecological sustainability that are posed by dependence on biomass, but it also discusses the range of social and political factors that affect household energy choices and their environmental consequences.

## Woodfuels and Poverty

Biofuel dependence is closely correlated with income, both among and within countries. Figure 18.1 shows how the prevalence of fuelwood as a *primary* source of household energy declines with increasing income in several African countries.[2] Fuelwood and other solid biofuels are linked to poverty because they are associated with risks, inconveniences, and cultural meanings that people in higher income strata may wish to avoid. The UNDP in its World Energy Assessment defined energy poverty as "the absence of sufficient choice in accessing adequate, affordable, reliable, high quality, safe, and environmentally benign energy services to support economic and human development" (Goldenberg and Johansson 2004). Fuelwood, while affordable for most of the world's population, often has an unreliable supply, it is inconvenient to use as a fuel and requires considerable space for storage, it is unsafe from a health perspective, has limited ability to support economic development and its widespread use can potentially degrade ecosystems and reduce the environmental services they provide.

[2] Fuelwood falls off as a *primary* fuel choice among wealthier households. However, some evidence shows that families do not stop using woodfuels altogether. Instead, they expand their fuel choice as they get wealthier by incorporating additional fuels into their energy mix (Masera et al. 2000; Pfaff et al. 2004).

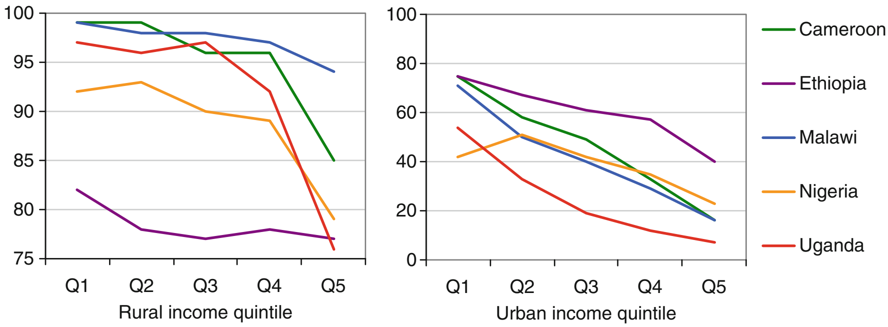



**Fig. 18.1** Prevalence of fuelwood as a primary energy source by income quintile in select African countries between 2001 and 2004. The graphs show rural (*left*) and urban (*right*) households. Note the vertical scales in each graph are different (Source: National demographic surveys reported in World Bank (2008))

As it is the main source of fuel of the world's "energy poor," fuelwood consumption is used as an indicator of poverty by development organizations. However, dependence on woodfuel is not just a result of poverty; it can also contribute to factors that reinforce poverty. It is a causal agent of preventable morbidity and mortality and it has a strong association with low educational attainment, both of which make it difficult for families to rise out of poverty (UNDP 2005).

Moreover, lack of modern energy services, which correlates with woodfuel dependence, places a burden on household labor. Economic activities are constrained because the energy to support a variety of income-generating activities is absent. However, it is important not to assume woodfuel reliance is always associated with a complete lack of access to modern energy services. There is wide regional variation. For example, in some developing regions, where biomass is the dominant fuel for subsistence needs, electricity is also widely available (IEA 2004). In such areas, access to electricity may support income generation, but families may continue to depend on woodfuels for the bulk of their cooking and space heating needs.[3]

## The Quality and Availability of Data on Woodfuels

Accurate data on fuelwood consumption in developing countries would be a powerful tool for policy makers designing legislation on topics ranging from energy systems to environmental conservation. However, fuelwood consumption data is

[3] This situation is common in parts of Mexico (Masera et al. 2000). Similarly, in rural China, where there has been near universal electrification, the majority of households continue to depend on biomass for their cooking needs (agricultural residues are more common than woodfuels, but the point still holds; see Zerriffi et al. 2008).

difficult to obtain for many reasons. In the developing world, fuelwood is collected and consumed by subsistence users who do not measure the amount or the species composition of their fuelwood stocks. Since fuelwood for domestic consumption is not often traded or sold in formal markets, uniform measurement standards and sales data simply do not exist.

Determining the amount of energy produced from fuelwood consumption is also difficult. Tree species have different calorific values (Harker et al. 1982). In addition, moisture content can vary greatly, which affects the mass of fuel consumed, as well as the useful energy that can be obtained from the fuel. Fuelwood consumption data based on weight must account for the species type and water content in order to give an accurate figure in terms of energy produced, but this is rarely the case. Moreover, the efficiency of energy conversion devices like wood-burning stoves varies enormously, so the estimates based on "typical" consumption rates of a small sample can be unreliable.

Despite the difficulties in obtaining reliable data on fuelwood consumption and energy production, resources are available that can assist policy makers in this realm. Surveys can provide a picture of a households' main source of energy. In recent years, some national censuses and demographic/health surveys have started to include questions about fuel choices. These data can provide a periodic nationally representative snapshot of household fuel choice. Unfortunately, data produced from these large-scale surveys are limited, in that they usually provide the household's primary fuel choice, but offer no insight into multiple fuel use, which is common even among poor populations.[4] In addition, large-scale survey data offers no insight into quantities of energy consumed at the household level. Some countries do conduct targeted surveys specifically exploring household-level energy consumption, but this does not appear to be common practice.

At the national level, aggregate energy consumption data is available from the International Energy Agency. The IEA publishes national and regional energy balances that offer detailed accounts of energy supply and consumption disaggregated by fuel-type and economic sector. Woodfuels are categorized in the "combustible renewables and waste" category (CRW), which includes all biomass fuels: those that are used in traditional applications, as well as feedstock used for modern applications like cogeneration or liquid biofuels.[5] In addition, the IEA disaggregates each energy type by sector, so residential energy may be analyzed separately (International Energy Agency 2008).

[4] For example, one nationally representative survey of Kenyan households found that 96% of the rural population used more than one fuel and 45% used three or more types of fuel (Nyang 1999).

[5] For the majority of developing countries, it is safe to assume that CRW consists almost entirely of traditional woodfuels and crop residues. One exception is Brazil, which uses biomass for a number of non-traditional applications: for example, the country produced nearly 19 billion liters of ethanol from sugarcane and generated over 14,000 gigawatt-hours of electricity from biomass feedstocks in 2005 (International Energy Agency 2008).

The FAO provides country and regional level data on woodfuel production in solid volume units (CMU) rather than in energy units. The FAO does not provide data on industries that rely on fuelwood for their energy supply, but it does provide estimates of country and regional level consumption calculated by subtracting exports from total production (FAOSTAT 2008).[6]

(a) Defining sustainability in the context of traditional energy systems

Sustainability has become an important concept in environmental governance, influencing policies ranging from industrial development to environmental conservation. The concept emerged in the 1970s, when it became apparent that the resource base upon which the global economy depended could not support the economy's rapid expansion (Kidd 1992). Economists began to study and model the conditions under which growth could continue in a world of finite resources (Cabeza Gutés 1996). These studies focused on capital, defined broadly as "produced means of production" (Costanza and Daly 1992), and differentiated the total capital stock into three categories: natural, social, and physical (or man-made) (Cabeza Gutés 1996). Natural capital consists of society's endowment from nature, which includes renewable resources like forests and non-renewable resources like fossil fuels. Physical capital includes money, as well as anything produced from natural capital ranging from buildings to machines. Social capital consists of intangible assets derived from interpersonal relationships within social networks and institutions. Social Capital is associated with structured forms of social interaction like formal educational systems, as well as unstructured everyday interactions that build social cohesion, trust, and reciprocity (Bourdieu 1985; Baker 1990).

Two different schools of thought on sustainability, each with different definitions, emerged based on the differentiation of capital. Strong sustainability regards natural capital as a collection of resources that provide functions that are not substitutable by social or physical capital. These functions include a host of ecosystem services ranging from erosion control to genetic diversity. Strong sustainability, therefore, is defined by maintaining the same level of natural capital for future generations. Weak sustainability views natural, social, and man-made capital as interchangeable, which implies that natural capital can be consumed as long as it maintains or increases the stocks of physical and/or social capital (Pearce and Atkinson 1993).

Fuelwood consumption is often portrayed as unsustainable because of its association with deforestation and/or forest degradation. From a strong sustainability perspective, these processes lead to a depletion of natural capital stock, which is not limited to trees, but includes the sum of all forest-related assets. If these assets are reduced for future generations, current extraction is unsustainable. However,

[6] Data from the IEA and FAO originate from different sources and often do not agree (see Bailis et al. 2005, supplemental online material for a discussion of this in the context of African woodfuel data).

unlike fossil fuels, forests are a potentially renewable resource. Forests can recover when wood is harvested for fuel: a form of "natural income" (Costanza and Daly 1992), which maintains the capital stock of the forest. If wood extraction is balanced with the forest's capacity to regenerate, then the capital stock is maintained. Forest management that satisfies strong sustainability criteria should take species composition and growing conditions into account, rather than simply maintaining a standing stock of biomass. This is a complex undertaking. Tropical and subtropical forests can be extremely heterogeneous and a great deal of variation can exist within a small spatial scale (Montagnini 2005).[7]

## Challenges to Sustainability in Woodfuel Systems

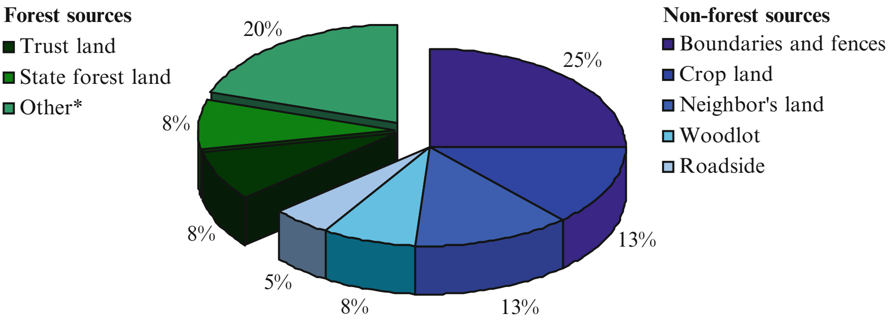
### *Ecological Sustainability*

#### Local Environmental Change

In the 1970s, global attention turned to energy issues as a series of price shocks that severely affected the world's economies. At roughly the same time, alarming rates of deforestation began to grab the world's attention (Bajracharya 1983). Analysts merged the two crises into a distinct environmental challenge, dubbed the "other energy crisis" (Eckholm 1975). This crisis revolved around fears that rates of wood harvest were exceeding sustainable yields in many of the world's developing regions. In response, development organizations published alarming reports predicting environmental catastrophe resulting from the so-called " firewood gap" unless drastic measures were taken, including unprecedented levels of tree planting and severe demand reduction programs (de Montalembert and Clement 1983; FAO 1978).

Closer scrutiny soon revealed that other socioeconomic drivers, primarily land clearing for cultivation and timber extraction, both exacerbated by expanding road networks, are more influential drivers of deforestation than wood energy use (Arnold et al. 2003; Geist and Lambin 2002; Kaimowitz and Angelsen 1998). In addition, numerous natural factors like rainfall, soil quality, and wildlife, interact with anthropogenic forces to influence tree cover in complex ways. Box 18.1 provides a description of how human and ecological drivers interact to influence land cover in savannah

[7] When discussing the impacts of woodfuels on forests, it is useful to draw a distinction between deforestation, the "direct human-induced conversion of forested land to non-forested land," and forest degradation, the "direct, human-induced, long-term loss (persisting for X years or more) or at least Y% of forest carbon stocks [and forest values] since time T and not qualifying as deforestation." Both definitions are from the IPCC (2003), but X, Y, and T are left to national or local-level decision makers to define. The distinction is important because woodfuel supply is rarely a sole cause of deforestation (Geist and Lambin 2002), but may be a driver of degradation. The distinction is also important for methodological reasons. Deforestation can be detected by remote sensing methods, but degradation very often cannot.




* "Other" includes purchased wood of unknown origin, which may be from forest or non-forest sources

**Fig. 18.2** Sources of firewood for rural households in Kenya in 2000

ecosystems, which provide woodfuels and numerous other sources of livelihoods for people across sub-Saharan Africa. These interactions challenge the idea of a direct link between woodfuel demand and deforestation.

In addition, problems arise among subsistence users if access to certain woodlands is denied or when woodlands are cleared as a result of other pressures. This can lead subsistence users to overexploit the little areas that remain accessible to them. Moreover, population and economic pressures can force people to shorten fallow periods or expand the area that they cultivate, which reduces both the time and space in which their home-grown wood accumulates. Hence, while energy demand may not be the primary cause of fuelwood-scarcity, scarcity still affects many who rely on woodfuels for subsistence needs.

Wood for subsistence use rarely comes from mature trees in forests or woodlands; people prefer gathering fallen branches and dead wood (Leach and Mearns 1988). People may also collect wood from their own household compounds or from fallow land to which they have access. Figure 18.2 shows sources of firewood identified by Kenyan households in a national energy survey. The majority report a dependence on non-forest sources of firewood, primarily from their own land (Ministry of Energy 2002). However, when woodfuel becomes commercialized, mature trees are often cut. This is common where woodlands are used to provide fuel to urban markets. For example, charcoal is a common fuel derived from wood that is carbonized (heated in an oxygen-deprived environment, so that full combustion does not occur and the volatile material in the wood is driven off). It is popular in many urban and peri-urban areas across the developing world and is associated with widespread clearance of woodlands (Girard 2002; Ribot 1993). Despite this association, empirical studies have shown that charcoal is not inherently destructive and that under good management, it may be produced sustainably (Chidumayo 1993; Hosier 1993; Young and Francombe 1991). However, charcoal is often produced illicitly; sound management is rare. Box 18.2 discusses charcoal production in Kenya, one of the world's leading charcoal producers, which struggles with the issue of sustainability in the charcoal trade.

**Box 18.1** Natural and Human Drivers of Land Cover Change in Woody Savannah

Africa's savannah woodlands provide woodfuel and other subsistence needs, as well as, some sources of commercial production for a large segment of the population. Savannah ecosystems under pressure from herbivory, rainfall variability, and fire can shift from grass-dominant to tree-dominant states or vice versa. Rainfall varies from year to year, and has direct and indirect effects on land cover (Scholes and Hall 1996). Precipitation affects the behavior of people and wildlife. In ecosystems initially dominated by grasses, abundant rains can lead to an increase in the quantity and quality of pasture, temporarily supporting higher concentrations of livestock and/or herbivorous wildlife. Grazing animals can promote the growth of woody biomass by removing the herbaceous layer, which competes for light and nutrients. Browsers, on the other hand, feed on young seedlings, preventing maturation, thereby maintaining the herbaceous layer. Soil types also influence these dynamics, as Breman and Kessler (1995):

> Woody plants vary in their response to grazing…On sandy soils or fluvial landscapes, intensive grazing may lead to an increase in canopy cover, but a strong reduction is also possible. On loamy soils especially in dry zones, canopy cover is reduced by intensive grazing because infiltration [of water] is reduced. However, the highest canopy covers occur on fallowlands and lands near natural or artificial water points (i.e. where grazing pressure is high). Higher rainfalls favor the more positive influences of grazing on woody plants (p. 45).

Fire is a perennial feature of savannah landscapes both as a natural and anthropogenic phenomenon. Fire interacts with rainfall and influences grazing in numerous ways:

> Fire leads to the loss of volatile compounds of nitrogen, carbon and sulfur. It tends to destroy woody seedlings and sensitive species, particularly those lacking seed adaptations, belowground reserves, and the capacity to sprout back. Rangeland systems…,where fire has been a regular feature for centuries, have a correspondingly fire-adapted species composition. In such systems periodic burning enhances the production of good grazing (Homewood and Rodgers 1991, p. 103).

The influence of rainfall and fire also depend on grazing intensity (Homewood and Rodgers 1991). Under moderate grazing, rainfall increases the quantity of herbaceous biomass. Under normal conditions, fires remove the herbaceous layer, but leave established trees and shrubs standing and promote germination of dormant seeds, thereby, reinforcing woody biomass cover. However, after heavy rains, above-normal herbaceous dry matter can cause intense burns, killing extant trees, and destroying the soil seed bank, causing a shift from woody to herbaceous cover. Both grasses and woody species can thrive, but there is a "competitive asymmetry" inherent in these systems such that either may establish dominance on small scales. For example:

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**Box 18.1** (continued)

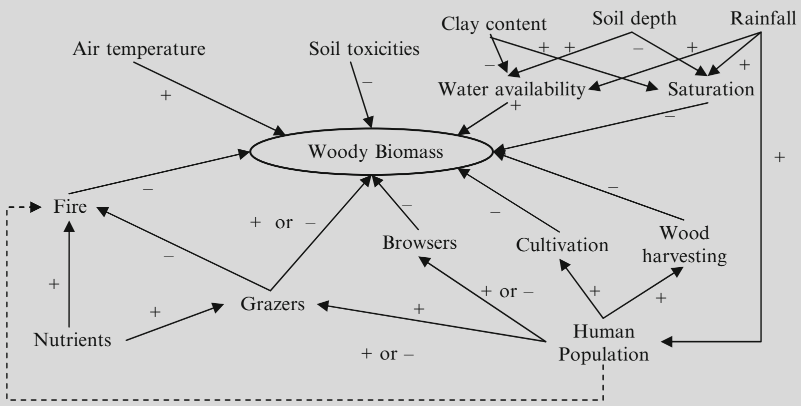


**Fig. 18.3** Factors that can increase (+) or decrease (–) woody biomass cover in savanna ecosystems (Source: adapted from Breman and Kessler (1995) and Scholes and Hall (1996))

> …mature trees out-compete grasses for light, water and nutrients, yet grasses out-compete small shrubs and tree seedlings (reducing establishment) and they increase the likelihood of fires which kill small trees…lead[ing] to structural instability. Often some degree of tree clumping takes place adding further complexity with conditions often very different between the under-canopy and inter-canopy areas (House and Hall 2003).

Some of these dynamics are illustrated in Fig. 18.3.

**Box 18.2** Charcoal in Kenya

Kenya relies on woodfuels for three-fourths of its primary energy supply (Fig. 18.4). Roughly half of the wood harvested for fuel is converted to charcoal. Despite its widespread use, woodfuel has largely been ignored by policy makers, particularly the supply side of the sector (Bailis et al. 2006). A strong association has been made by the press and the government between charcoal and deforestation (Ecoforum 2002; Okwemba 2003). Unfortunately, little can be said with certainty about the degree to which Kenya's exploitation of wood energy is leading to permanent forest loss. Reliable data is very difficult to obtain. It is certain, however, that the country lacks an effective set of policies to promote or enforce sustainable woodfuel management. This void leads to a great deal of ambiguity in the woodfuel sector. Some charcoal regulations are in

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**Box 18.2** (continued)

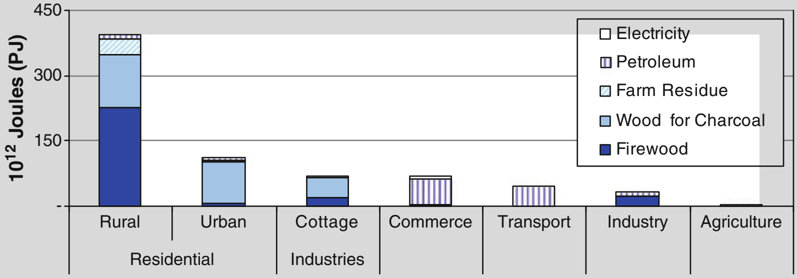


**Fig. 18.4** Kenya's energy supply by fuel and sector in 2000 (IEA 2003; Ministry of Energy 2002)

place at the provincial or district level, but these lack transparency and suffer from inconsistent enforcement. Consequently, in many parts of the country, charcoal is illegal to produce and transport, but it is legal to sell, buy, and consume. Such ambiguity discourages investment in the trade, encourages unsustainable practices, and fosters corruption.

For example, in Narok district, a major charcoal production zone, a ban on commercial charcoal transport was in effect between 2003 and 2005. Despite the ban, the district provides as much as 30% of Nairobi's charcoal, with 10–20 lorries ferrying thousands of 40 kg sacks to the city every day (Bailis 2005). The ban, which was meant to protect nearby Mau Forest, a high-value conservation area, was circumvented through bribery, which reached such high levels that as much as 25% of the retail price of each sack of charcoal was fraudulently captured by local officials (Bailis 2005). Ironically, Narok's charcoal does not originate from the forest that the transport ban was meant to protect. Rather, it is harvested from parcels of woody savannah that were formally pastoral, but had been subdivided and allocated to the district's Maasai population throughout the 1990s. This land is private land that would likely be cleared in the absence of charcoal production: charcoal simply facilitates the process.

Woodfuel, particularly the charcoal trade, provides direct employment for as many as 200,000 people across Kenya at different stages of the supply chain (Mutimba and Barasa 2005). For some with little or no land to farm, charcoal provides full-time employment. For others, it presents a source of income when farm production is low or when a bit of extra cash is needed. Thus, woodfuels are a critical part of the economy, not only because of their contribution to household production, but also because of the livelihoods of woodfuel suppliers.

Woodfuel dependence will persist in Kenya; whether it can be managed sustainably is an open question. To promote sustainability, regulations governing the woodfuel trade must be rationalized and clarified to remove the legal ambiguity that currently exists. Investment in woodfuel production must be encouraged, so that the private sector can participate in woodfuel provision.

## Woodfuels and Global Change

In addition to local environmental impacts, the scale at which woodfuel consumption occurs has implications for global change. Wood harvesting, fuel processing, and final combustion create a flow of greenhouse gases (GHGs) from terrestrial stocks to the atmosphere. Post-harvest management of woodlands may also result in GHG emissions. On the other hand, carbon is sequestered by the regeneration of harvested trees, thus, the net emissions of GHGs from the wood-energy fuel cycle depend on the degree of sustainability with which the fuel is harvested. Identifying the degree of sustainability of the woodfuel harvest is challenging and few rigorous examples of this research exist. Box 18.3 discusses one effort, which utilized multi-scale spatial analysis of woodfuel supply and demand to identify local-level imbalances.

However, full regeneration of harvested trees does not assure GHG-neutrality. Additional emissions occur, because typical wood combustion devices such as household stoves in the developing world cannot achieve full combustion, which results in emissions of $CH_4$ and $N_2O$, as well as GHGs that are not controlled under current climate change policies, but nevertheless have an impact on radiative forcing, such as CO, non-methane hydrocarbons, and aerosols.[8] Furthermore, charcoal production, which utilizes roughly 15% of woodfuel harvest worldwide (FAOSTAT 2008), emits considerable amounts of non-$CO_2$ GHGs (Kituyi et al. 2001; Pennise et al. 2001; Bertschi et al. 2003; Brocard et al. 1996).[9]

Based on numerous studies of biomass emissions under lab and field conditions, it is estimated that $CO_2$ contributes roughly 60–70% of the "tree-to-stove" emissions from fuelwood and 30–40% of the tree-to-stove emissions from charcoal (Bond et al. 2004; Bertschi et al. 2003; Brocard et al. 1996; Pennise et al. 2001). Thus, regeneration of harvested trees reduces the impact from $CO_2$, but can not fully offset the impact from the other GHGs.

The IPCC's Fourth Assessment Report notes that some of the emissions from land use change (LUC) are the result of "traditional biomass use." However, the assessment departs from its usual rigor by assuming that 90% of the traditional biomass harvest is "from sustainable biomass production." The remaining 10% of global harvest is "non-renewable" by default (the IPCC bases this on assumptions made in International Energy Agency 2006a). Based on this assumption, the IEA

[8] $CH_4$, $N_2O$, CO, non-methane hydrocarbons, and BC aerosols have a larger warming impact than a molar equivalent quantity of $CO_2$. OC aerosols have a cooling effect, but these only partially balance the warming impact of BC species (Bond et al. 2004). Each of these compounds has a larger warming impact than a molar equivalent quantity of $CO_2$ (with the exception of OC aerosols) (IPCC 2007). Therefore, when fuel-bound carbon is emitted in one of these forms rather than $CO_2$, $CO_2$ sequestration through future wood growth does not fully counterbalance the warming effect of those pollutants.

[9] Estimates of global woodfuel production and the fraction of woodfuel that is utilized for charcoal vary widely (see Bailis et al. 2005, for a description of limitations in this data).

**Box 18.3** Spatial Analysis of Woodfuel Supply-Demand Imbalances in Central Mexico

Historically, studies of woodfuel balance (supply and demand) have utilized either national or regional data or micro-level case studies conducted in specific localities. However, complex relationships between fuelwood supply and demand lead to impacts that are heterogeneously distributed in space and time. Generalized approaches used to determine national or regional wood energy balances are unable to provide information on the spatial distribution of areas suffering from extreme supply–demand imbalances. Localized case studies may be able to identify such "hotspots," but cannot be extrapolated, as fuelwood use and associated impacts can differ substantially, even between neighboring localities.

This study used a spatially explicit method to assess environmental and socio-economic impacts associated with traditional fuelwood use in Mexico in order to identify woodfuel "hotspots": that is, individual localities with high woodfuel consumption and insufficient biomass resources (Fig. 18.5). In the first stage, a multi-criteria analysis was conducted in order to analyze Mexican counties according to seven indicators: number, density, and annual population changes of fuelwood users; percentage of households using fuelwood; resilience of consumption; trends in land use and land cover change; and the balance between supply and demand. The national fuelwood balance – a key value when comparing countries – was extremely positive (165 million tons per year). Compared to Southeast Asia and sub-Saharan African countries, Mexico is not in a crisis situation in terms of fuelwood use and its associated impacts. However, the spatial analysis identified 304 counties (out of a total of 2,424) with negative or close to zero balances. These were grouped into 16 *hot spots*. Approximately 6.3 million fuelwood users live in these counties, which constitutes 25% of the nation's fuelwood users in 2000.

In the second stage, one fuelwood *hot spot* in Michoacan State was selected and a grid-based model was developed in order to identify individual localities with high fuelwood consumption and insufficient supply. The analysis also gave a robust and statistically confident estimate of the non-renewable biomass (NRB) fraction of fuelwood extraction by locality (a critical value to estimate baselines in carbon offset projects) (Fig. 18.6). Ground-truth efforts validated these findings. Importantly, large variations in NRB were found in neighboring communities, which demonstrates that spatial patterns of fuelwood supply and demand are highly site specific. This work shows the value in multi-scale assessments of woodfuel supply and demand in order to focus action on the most critical locations.

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**Box 18.3** (continued)

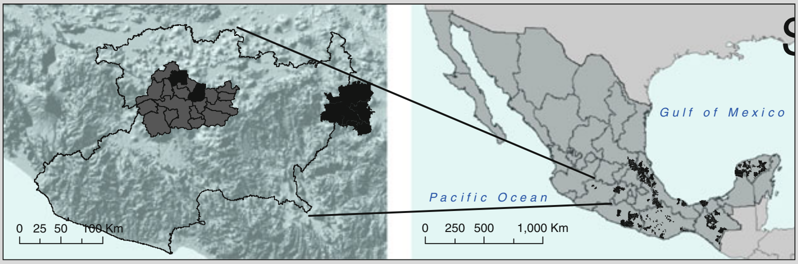


**Fig. 18.5** Study area: the Purhepecha Region. Notes: *Black shapes* in each map represent high priority counties following the national-level assessment (Ghilardi et al. 2007). In the *left-hand* map, counties of the Purhepecha Region in the north-west of Michoacán State, are highlighted in *dark gray*

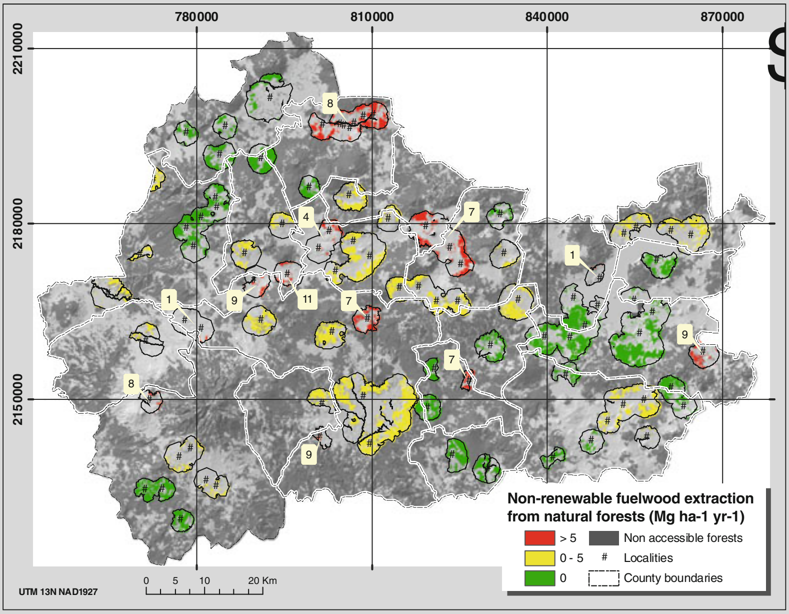


**Fig. 18.6** Pressure over natural forests due to fuelwood extraction on a non-renewable basis from accessible areas considering walking fuelwood gatherers. Notes: Highlighted *red, yellow and green* areas within accessible areas correspond to accessible forests. *Dark-gray* areas correspond to non-accessible forests. Labels show the expected time in years for depletion of half the fuelwood stock available from forest areas (Source Ghilardi et al. 2008)

estimates that global woodfuel use contributes to approximately 2% of total global emissions (International Energy Agency 2006a, section III.6).[10] This is roughly equivalent to the emissions from the transport sector in the European Union (World Resources Institute 2008).

Of course, this estimate ignores the interactions between wood harvest for energy and other drivers of LUC discussed above. Moreover, the relationships between proximate causes of land cover change and structural drivers of change like demography, political economy, and technology make it difficult to attribute a specific value to the net emissions from woodfuel demand alone.

Additional aspects of woodfuel sustainability are linked to the social conditions in which production and consumption occur. These include struggles over access among producers and consumers of forest resources for energy and other uses. Social sustainability also extends into the health and well-being of woodfuel users. Each of these are discussed briefly below.

### Political Ecology and Resource Access in the Context of Woodfuels in Developing Countries

Woodfuel provision is a critical component of household production, both for domestic use and for provision to the market. Thus, woodfuels are linked very closely to the livelihoods of poor rural populations. In locations where woodfuels or other forest resources are extracted for commercial sale, local users may find that their own access to energy for subsistence needs is contingent on distant markets, state agents, and powerful business interests (Ribot 1999; Bailis 2005).

As was discussed above, woodfuel provision has strong associations with environmental degradation. Environmental impacts, whether real or perceived, often generate attempts by governments to regulate or control access to those resources. For example, charcoal and firewood dealers may be required to obtain permits to ensure that the supply is from a sustainable source. Those attempts may be subverted by poor enforcement, corruption, and/or a failure to incorporate local knowledge and institutions in regulatory design (Ribot 1999; 2004; Dove 1992; Robbins 1998). The illicit nature of woodfuel provision systems tends to make them opaque to outsiders (see the discussion in Box 18.2, which describes charcoal production in Kenya).

The benefits that people obtain by playing a role in these markets are mediated through the degree of access that they maintain. Access is mediated by mechanisms that are both legal and extra-illegal, as well as an array of "structural and relational" factors that include technical capacity, markets for land, labor and capital, as well as social identity and social relations (Ribot and Peluso 2003). These factors actively

[10] The authors checked the IEA's estimate by considering global fuelwood and charcoal consumption as reported by both the FAO and IEA (FAOSTAT 2008; International Energy Agency (IEA) (2007)) and the IEA's assumption that 10% of the global woodfuel harvest was unsustainable. Taken together with published emissions factors for wood combustion and charcoal production/combustion (Bertschi et al. 2003; Brocard et al. 1996; IPCC 1997; Pennise et al. 2001; Smith et al. 2000), we estimate that net GHG emissions from woodfuel combustion ranged from 1 to 2.8% of global GHG emissions

shape dynamic systems of provision that are distributed over space and changing over time (Leslie and Reimer 1999).

Understanding the flow of benefits from woodfuel provision is not only of theoretical importance. It is also of critical relevance. Many interventions attempt to improve rural livelihoods and environmental outcomes by changing the mechanisms of access for certain groups or actors. A lack of understanding of the practices within and between groups of actors in the commodity chain has led to failure of many interventions. For example, in parts of West Africa, devolution of control over state-owned forests has led to increased control by local communities, including management that supplies woodfuel markets. Under such systems, woodfuel dealers typically pay higher prices than when they have access to resources not under community management. However, not all accessible forest has been brought under full community control and influential outsiders, including officials from the Forest Services of numerous countries, still capture disproportionate benefits of the trade, particularly where local community cohesion is weak (Kerkhof 2002).

Thus, interventions may not fail completely. However, they may still have unintended, potentially negative environmental impacts and/or negative outcomes for less powerful economic players (Schroeder 1993). Some of these dynamics are explored in Box 18.4, which gives an example of woodfuel management in Senegal.

**Box 18.4** Incorporating Energy Needs in Conservation Policy: The Saloum Delta National Park, Senegal

The Saloum Delta National Park (SDNP) in Senegal has a tradition of conservation dating back to 1935, when it was made a forest reserve under the French colonial forestry code in order to protect it from what the French deemed the "immemorial abusive use by natives" (cited in Ribot 1993). In 1981, the size of the SDNP was increased to include a large portion of the Saloum delta and was later classified as a UNESCO Man and Biosphere Reserve, as well as a RAMSAR site. Despite these conservation efforts, conflict over wood extraction between local people and forestry officials persists (Ribot 1993; Chatellier 2007).

While recent national surveys have documented that Senegal's urban populations use LPG as the dominant cooking fuel (ENDA 2005; Macro International 2008), nearly 99% of the rural population in the area surrounding the SNDP, relies on fuelwood as the main cooking fuel (Chatellier 2007, See Fig. 18.7). Fuelwood is also used in the region for commercial activities, such as shell fish processing, fish smoking, and the production of shell lime, a cement substitute. Regional surveys suggest the presence of a fuelwood shortage; the majority of subsistence fuelwood collectors reported the need to travel longer distances and spend more time searching for fuel than 10 years earlier. With accessible fuelwood far from village centers, fuelwood markets have materialized. Thus, fuelwood is now a commodity with a well-known price, which has

(continued)

**Box 18.4** (continued)

**Fig. 18.7** Images from communities adjacent to Saloum Delta National Park in Senegal: a woman with purchased fuelwood (*left*) and a shell-lime kiln (*right*) (Source: J. Chatellier)

encouraged professional fuelwood collectors, with access to better tools, transportation, and labor, to enter into the market. Fuelwood for cooking needs, once a subsistence product, has become commercialized; families spend cash instead of labor to meet basic energy needs. Broader economic effects also affect local markets. For example, a recent spike in cement prices led to a boom in shell lime production, which requires vast amounts of fuelwood to process. This added source of demand exacerbates the local fuelwood shortage and drives up prices.

Fuelwood extraction in the SNDP is banned under the Senegalese forestry code, which prohibits resource extraction from national parks even at the subsistence level. Despite the law and a visible presence of park officials, commercial fuelwood extraction, sale, and consumption take place openly. Park officials devote resources to regulating subsistence-level extraction by women who remove mostly deadwood and coppiceable shrubs by requiring that they obtain "free" permits. The permit system dates to the 1930s, when the colonial government used it to assert its ownership of the forest (Ribot 1993; Chatellier 2007). In contrast to the regulations on subsistence collectors, park officials turn a blind eye to the harvest of entire trees for commercial activities, which are often managed by local elites. The criminalization of energy needs in communities adjacent to national parks has created a divide between locals and park officials making future collaboration on conservation difficult. A sustainable silviculture management program, designed to meet the energy needs of local communities, could be one way to meet local fuelwood needs and maintain conservation efforts as it would reduce the current ecologically destructive practice of selective logging (Uhl and Vieira 1989).

#### Health and Social Welfare

As was mentioned previously, small-scale combustion devices burning solid fuels can not achieve full combustion and, as a result, release numerous pollutants. In addition to having a climate impact, stoves vented directly into the indoor environment result in harmful concentrations of indoor air pollution. Solid fuel use has been shown to cause elevated risks of acute respiratory infection (ARI), chronic obstructive pulmonary disease, and some types of cancer.[11] The WHO estimates that diseases attributable to smoke from solid fuels contribute nearly 3% of the global burden of illness and death (WHO 2002).

These effects are concentrated within particular populations. As a result of the division of labor within most households in the developing world, exposure occurs disproportionately among women and young children (WHO 2002). Other risks from woodfuel use, like burns, can affect young children in particular. In addition, the risk of injury from gathering and transporting heavy loads of fuel over long distances, as well as exposure to possible harassment for girls and women gathering wood far from home can arise. However, evidence of these risks is only collected anecdotally, and, thus, they are not included in official statistics (Diaz et al. 2008).

## Interventions in the Traditional Energy Sector

As was discussed above, concern about woodfuels initially focused on the perceived link between woodfuel consumption and deforestation. This dates at least to the 1970s, but the interest in forest conservation gradually subsided and a focus on public health emerged. Much more recently, the link between woodfuels and forest conservation has re-emerged in the context of GHG emission reductions. Each of these types of intervention are discussed below.

### *Interventions Linking Woodfuels and Forest Conservation*

#### Supply-Side Interventions

For many, the obvious response to woodfuel scarcity is to plant trees. In some cases, this response coincides with the needs of communities that are dependent on wood for energy, but that is not always the case. Planting and maintaining trees can be a

[11] The only conclusive association between cancer and IAP is lung cancer from exposure to coal smoke. Health professionals suspect that other forms of cancer may also be caused by exposure to smoke from solid fuels, but the epidemiological evidence is inconclusive. Similarly, asthma, tuberculosis, cataracts, and low birth weights are suspected, but not yet proven conclusively (Smith and Mehta 2003; Smith et al. 2004).

time consuming, labor-intensive process for local communities. People are unlikely to plant trees for energy if alternative sources exist, such as crop residues. Similarly, if land can be put towards more lucrative uses; planting trees for firewood may be seen as "burning money." Tree planting as a response to wood scarcity is, in any case, complicated by local property institutions. In some places, property rights associated with trees and their products are separable from rights to the land on which the trees grow (Fortmann and Bruce 1988). Planting trees may represent a claim of land ownership, and result in disputes. In addition, in many post-colonial societies there is a long history of land appropriations and forced evictions predicated on real or perceived environmental crises (Leach and Mearns 1996). Thus, any intervention, however, well intended, may be viewed with suspicion (Skutsch 1983).

If tree-planting is introduced as a means of easing the pressure that demand for woodfuels puts on forests, interventions may be either through state-run, community, or farm/ household-level forestry. Many state forestry institutions have a history of antagonistic relations with local communities (Castro and Nielsen 2001; Skutsch 2000). Nevertheless, some governments have successfully established woodlots or managed forests specifically for community wood production (FAO 2003). However, establishing tree plantations is expensive, particularly when state bureaucracies are involved, and highly centralized state-run forestry agencies are not usually an economically feasible way to mitigate woodfuel scarcity. On the other hand, if state-owned forests are already established (for example, in reserves established for timber production), the state can ease wood scarcity by allowing local communities access to dead wood, fallen trees, and pruned branches or by devolving a section of the forest to community control.

Community forestry (CF) contrasts with state forestry in that forest management is partially or wholly vested in the community. Many variations of CF exist. The managed trees may be a section of natural forest, a plantation or a wood-lot. Land may be land held in common, or it may lie on state-owned land with management responsibilities vested in the community. Fuelwood provision is one of many possible dimensions of CF, but energy is rarely the sole purpose of establishing community control. Some CF arrangements limit communities to non-commercial/ non-timber uses: for example, rights to graze livestock, fish, hunt, and extract a variety of forest products like food, medicine, leaves, and thatch. Other community forestry systems vest commercial management rights in communities including the right to sell timber concessions or harvest timber commercially themselves as in Mexico, Laos, and Vietnam (Bray et al. 2003; Sunderlin 2006).

Wood scarcity can also be mitigated by tree planting at the household level. Smallholders throughout the developing world maintain wide varieties of trees on their own land (Chambers and Leach 1989). The majority do so without outside assistance, though outside intervention can help to provide seeds or seedlings, as well as technical advice. As with CF, trees on farms are rarely used only as sources of fuelwood. Agroforestry, which integrates trees with cultivation and livestock systems, is particularly effective for maintaining trees on the homestead (Montagnini 2006).

**Demand-Side Interventions**

In addition to tree planting, the perceived link between fuelwood consumption and deforestation led to the development and dissemination of fuel conserving cookstoves. Early views presumed that traditional cookstoves were inherently inefficient and attempted to improve upon them by improving combustion efficiency and heat transfer. To date, hundreds of varieties of cookstoves have been developed and hundreds of millions of stoves are said to have been disseminated throughout the developing world. The vast majority of these are in China. Many programs have not succeeded, or have had problems scaling up. Early interventions tended to focus on engineering solutions, but failed to address social issues in which household energy use is situated (Barnes et al. 1994, also discussed in the chapter by Doll, this volume). Few realized that in the hands of an experienced cook, a traditional "three-stone" fire can be as efficient as many heavily engineered stoves. The behavior, perceptions, and motivation of the cook are important determinants of fuel consumption that were largely overlooked (Crewe 1997).

A few programs that were developed during the 1980s have had a lasting impact. In addition to China's massive National Improved Stove Program (NISP) (Sinton et al. 2004; Smith et al. 1993), the Kenyan Ceramic Jiko was also relatively successful (Hyman 1987; Kammen 1995). Some reasons for the success of each program include a slow transition from heavy state or donor support to commercialization so that after a time, stove construction and sale were shifted to the private sector. Importantly, this shift was supported at various stages by substantial research and development, stove marketing, external monitoring, and evaluation, and, in China's case, quality control and certification (Bailis et al. 2008).

## *Interventions in Household Energy and Health*

Both the successes and failures of past projects offer lessons for a new wave of household energy interventions currently underway. These interventions focus on reducing the burden of disease caused by cooking with biomass fuels by improving combustion, venting emissions outdoors, or switching to cleaner fuels. Numerous studies have shown that these strategies can reduce IAP substantially (Chengappa et al. 2007; Dutta et al. 2007; Ezzati et al. 2000; Masera et al. 2007).

The task remains to scale up dissemination of improved stoves. Numerous projects are underway across the developing world with varying levels of donor support.[12] Among the donor community, recent activities are oriented toward

[12] There are several web-based sources of information about household energy and health projects including the Household Energy Network (HEDON) at http://www.hedon.info/goto.php/index.htm, SparkNet at http://sparknet.info/home.php and an on-line community of improved stove practitioners at http://www.bioenergylists.org/.

commercialization of stove dissemination. This reflects a shift that has occurred in development practice more generally, where emphasis is placed on business-like approaches rather than models that rely on donors and subsidies (Hoffman et al. 2005; Bailis et al. 2008). Whether this shift will facilitate broader adoption of cleaner household energy technologies remains an open question.

### *Interventions Linking Woodfuels and GHG Emission Reductions*

In addition to the recent attention on public health in household energy interventions, there has also been growing interest in the traditional energy sector as a means to reduce GHG emissions. Academic studies have quantified the differences in emissions between traditional and improved stoves in both lab (Bertschi et al. 2003; Brocard et al. 1996; Pennise et al. 2001; Smith et al. 2000) and field settings (Johnson et al. 2008; Roden et al. 2006). Yet, net emissions reductions depend on forest management, as well as, emissions from stoves (Bailis and Barasa 2008).

Despite the challenges, some carbon markets are accepting carbon offsets generated from substituting traditional stoves with improved ones. The Clean Development Mechanism (CDM) of the Kyoto Protocol has recently accepted two methodologies that cater to this type of project, after a long period in which improved stoves were not considered suited to CDM, because woodfuel themselves were considered to be unsustainable. However, despite this change, very few cookstove projects have yet entered the CDM pipeline (Fenhann 2008). In addition, a voluntary offset methodology has recently been accepted by the CDM Gold Standard, an organization that certifies carbon offset projects that maximize social and environmental co-benefits (ClimateCare 2008). The traditional energy sector has the potential to yield emission reductions with substantial co-benefits and revenue generated from the sale of offsets, which could assist with scale-up of stove projects that often struggle to achieve widespread adoption.

## Conclusions

This chapter has discussed multiple dimensions of sustainability relevant to woodfuels. In its most narrow conception, a concern about sustainability in the context of woodfuel use may be limited to local environmental degradation. However, as we argue, sustainability has much broader implications. First, environmental sustainability extends across different scales, including regional impacts and global change. Moreover, the challenge of woodfuel sustainability extends into social and political spheres, including poverty and livelihoods, public health, and social relationships.

In this section, we present policy options relevant for each of the aspects of sustainability discussed above.

Promoting woodfuel sustainability requires an understanding of the drivers of forest degradation and the role of woodfuel harvesting as one of several possible pressures on forest resources. This knowledge is required at a scale that is meaningful to woodfuel users. As Ghilardi explains in his discussion of fuelwood *hotspots* in Mexico (Box 18.3), woodfuel–forest interactions can be very heterogeneous across relatively small scales. Communities with similar social characteristics and woodfuel demand may manage forest resources very differently. Analyses of local heterogeneity can be indispensable in identifying local-level drivers of change, as well as prioritizing areas for intervention.

In addition, in woodfuel-dependent communities where forest degradation is apparent, policy makers should not assume *a priori* that woodfuel demand is the sole or primary driver. Multiple pressures on forest resources can interact with, and supplant, woodfuel extraction as drivers of environmental change. Only local-level research can truly identify causes of forest degradation and lead to solutions.

In cases where woodfuel extraction is identified as a cause of forest degradation, a range of supply and demand-side interventions are possible. To address supply-side challenges, the devolution of forest management to local communities has proven to be effective, provided that communities are sufficiently empowered with strong institutional arrangements and sufficient resources (Ribot 2004). Extension services can support such efforts by providing technical advice and training.

Demand side challenges include technological and behavioral changes that promote cleaner combustion, improve end-use efficiency, and/or shift wood-dependent households toward other sources of energy. These interventions also have the benefit of addressing some of the social sustainability challenges linked to woodfuel-dependence. Efficiency improvements can lower the costs of cooking by reducing the time and/or expense required to procure fuel, and cleaner combustion can reduce exposure to harmful pollutants leading to lower incidence of disease.

Both supply and demand-side interventions also carry global environmental benefits. Supply-side interventions can enhance carbon sinks by promoting afforestation and reforestation or reduce future emissions by avoiding deforestation and degradation. Demand-side interventions can also reduce emissions in multiple ways. First, efficiency improvements reduce the amount of fuel needed for a given cooking task, which reduces pollution. Second, when demand-side interventions promote cleaner combustion, emissions of pollutants with high global warming impacts are reduced.

However, describing potential benefits from interventions that enhance the sustainability of woodfuel use is easy. The true challenge lies in operationalizing interventions at a level that is commensurate with the scale of the challenge. Saving existing forests and planting trees are both universally promoted environmental objectives, but both activities have proven difficult to implement on a grand scale. Similarly, with a few notable exceptions, reducing woodfuel demand by promoting technical and/or behavioral change is proceeding at a very slow pace despite analyses that show such interventions are extremely cost-effective ways of addressing environmental and public health challenges (World Health Organization 2007).

There are numerous barriers to scaling up efforts to promote woodfuel sustainability. For example, many of the negative impacts associated with woodfuel dependence – forest degradation, as well as labor demands and health impacts among highly marginalized populations – often fall outside of the formal economy for which decision makers typically design policy. This stands in contrast to recent approaches in development interventions which have become increasingly market oriented: for example, the commercialization of improved cookstoves and monetization of ecosystem services (see the chapters on Payments for Ecosystem Services, Volume 2). Until the problems associated with dependence on unsustainable woodfuels are fully understood and, to the extent that is possible, quantified, commercialized solutions are unlikely to be effective.

Other barriers arise because the nature of woodfuel sustainability is highly contingent on local circumstances. Locally specific social-environmental factors confound attempts to develop and deploy “best practices”, as discussed in the chapter by Ganz et al., this volume. As Ghilardi explains in the case study from Mexico described in Box 18.4, local woodfuel management practices and associated environmental impacts can vary a great deal within a politically defined region that is otherwise culturally and economically similar.

However, despite numerous barriers, there are several reasons to be optimistic about the prospects of sustainability in the woodfuel sector. First, the breadth of tools required to better assess the benefits of more sustainable household energy utilization has expanded a great deal in recent years (Disease Control Priorities Project 2006; Smith et al. 2007; World Health Organization 2007; Ghilardi et al. 2007). Second, many actors in emerging carbon markets have turned their attention to the household energy sector as a promising area to create carbon emission reductions that also carry substantial social benefits. This has raised the profile of household energy among policy makers and created incentives to develop more accurate assessment methodologies to better understand the circumstances in which woodfuel utilization contributes to forest degradation and loss. In a third and related point, the emerging discussions of reducing emissions from deforestation and forest degradation (REDD) in the context of climate change mitigation (see chapters by Rumbaitis del Rio, this volume, Jenkins, Volume 2, and Estrada and Corbera, Volume 2) has also turned attention toward the household energy sector in certain places. However, currently, carbon markets are limited to project-level interventions, which almost always occur at a local scale, while the REDD discussions will require a much needed dialog at the national scale.

Woodfuel dependence in developing countries is unlikely to decrease in the near-term and many barriers to enhancing woodfuel sustainability are still well-entrenched. Nevertheless, new assessment methods and changing approaches to environmental management have shifted the terrain slightly in favor of greater sustainability. Whether these changes translate into real improvements in environmental quality and social welfare for woodfuel-dependent communities remains to be seen.

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