



## How can emissions from woodfuel be reduced?

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- Unsustainable harvesting and combustion of woodfuel can aggravate climate change but, if woodfuel replaces fossil fuel, it can become part of the solution.
- Policies to reduce the demand for woodfuel (promote more efficient cooking stoves, substitute other fuels) can be effective if combined with and supported by other policies.
- Supply side measures (efficient woodfuel production and plantations) can also help reduce emissions, but there is no substitute for better control of harvesting.

### Introduction

Unsustainable harvesting and combustion of woodfuel<sup>1</sup> aggravate global climate change. But, since climate change is mainly caused by burning nonrenewable fossil fuel, a switch to sustainable woodfuel could mitigate climate change. This chapter reviews how woodfuel can aggravate or

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<sup>1</sup> The term 'woodfuel' is used here to cover both 'fuel wood' and 'charcoal', but not the use of wood biomass as feedstock for other sources of energy such as gas or liquid fuels, or for direct combustion to produce electricity.

mitigate climate change and discusses possible measures to limit its negative climate impacts.

Given the importance of woodfuel, both as a source of and a sink for greenhouse gases (GHGs), it is striking how little attention is paid to it in the REDD+ literature. There is general agreement that collecting fuel wood contributes to forest degradation, particularly in Africa, and especially in the drier forests of sub-Saharan Africa (Kanninen *et al.* 2007). The Meridian Institute (2009a) estimated that the climate benefits from stopping 'biomass extraction for fuel (fuel wood and charcoal) at rates greater than regrowth' would be just 5–8% less than those from stopping deforestation. Some investigators warn that focusing too much on the collection of woodfuel as a driver of degradation may lead to interventions that harm the poorest people by limiting their access or driving up prices (Griffiths 2008; Lovera 2008; Peskett *et al.* 2008).

This chapter starts by looking at how woodfuel contributes to GHG emissions. Next, we review the current and projected use of woodfuel (i.e., fuel wood and charcoal) in developing regions, and discuss factors affecting demand. Finally, we outline potential interventions on the supply and demand sides that could be considered when designing national REDD+ policies.

## Climate change and woodfuel

Woodfuel contributes to GHG emissions through unsustainable harvests and the combustion of biomass. Whether or not the supply of woodfuel from forests and woodlands is sustainable depends on the difference between the harvest rate and the growth rate. When the extraction rate is greater than the rate at which the biological system regenerates biomass, forest or woodland becomes degraded. For the African *miombo* type woodland, woodfuel yields of about 2–3 t/ha per year are common (Campbell 1996; Hofstad 1997). Namaalwa *et al.* (2009) estimate that yields in Ugandan *Combretum* woodlands are about 2–4 t/ha per year. Aggressive fuel wood and charcoal producers often extract woodfuel at much higher rates where demand is high. Consequently, the density of woodland biomass becomes reduced (Luoga *et al.* 2002) resulting in net CO<sub>2</sub> emission. In Uganda, the density of air-dry biomass in large areas of woodland falls on average by 3 t/ha per year (MWLE 2002).

Since fuel wood is heavy and bulky, it is often made into charcoal if it is to be used some distance from the forest. Where wood is used to make charcoal, harvesting can take place over a much larger area than where wood is gathered for local use. Where woodfuel goes to make charcoal, harvesting could be maintained at a level below that required to regenerate the wood. However, if there is no control of harvesting, or if control is weak, operators are likely to harvest as close to markets as they can to maximise their profit. In many

places, degradation is the inevitable result, such as around Kampala (Knöpfle 2004), Dar es Salaam (Monela *et al.* 1993), Blantyre (Matope 2000) and in the Zambian Copper Belt (Chidumayo 1989).

GHGs are emitted when woodfuel combusts. Dry wood contains about 50% carbon, but the carbon content of growing trees is much lower, as they contain a much higher proportion of water than dry wood. When one tonne (metric ton) of dry wood burns or decays, 1833 kg of CO<sub>2</sub> is emitted. In the pyrolysis of wood into charcoal, carbon is emitted to the atmosphere in the form of CO<sub>2</sub>, carbon monoxide (CO) and methane (CH<sub>4</sub>). Of these, CH<sub>4</sub> is particularly important as its global warming potential is about 21 times that of CO<sub>2</sub>. Making charcoal in earth kilns normally results in about 50% of the woodfuel carbon being stored as charcoal, 25% emitted as CO<sub>2</sub>, and the rest emitted as methane or other gases, or left as ash or particles in the air (Lamlom and Savidge 2003).

Emission of black carbon from biomass combustion may exacerbate the effects of climate change in Asia (Venkataraman *et al.* 2005). Carbonaceous aerosols cause strong atmospheric heating and large surface cooling that affect the South Asian climate as much as GHGs. Gustafsson *et al.* (2009) found that biomass combustion produced two-thirds of the bulk carbonaceous aerosols, and more than half of the black carbon.

### **Box 19.1. Effects of forest degradation on biomass and carbon stocks**

Luoga *et al.* (2002) found that the standing volume in *miombo* woodland in a Tanzanian forest reserve was 47 m<sup>3</sup>/ha. In comparable public land less than 2 km from a public highway which was exploited for charcoal, the standing volume was 14 m<sup>3</sup>/ha, while biomass density was 8.8 t/ha. In woodland more than 10 km from the highway, the standing volume was 22 m<sup>3</sup>/ha, while biomass density was 13.8 t/ha. The authors concluded that the level of harvesting in public lands is not sustainable as the annual removal of 6.38 m<sup>3</sup>/ha far exceeds the mean annual increment of 4.35 m<sup>3</sup>/ha.

The stakes are even greater in more humid forests. Palm *et al.* (2004) reported aboveground, time-averaged C stocks of different land use systems in Indonesian and Peruvian rainforest zones. Undisturbed forest in the two locations contained 306 and 294 t C/ha, respectively. Managed and logged forest held 93 and 228 t C/ha, respectively, while shifting cultivation and crop fallows contained an average of 7 to 93 t C/ha in Peru. Rotational rubber agroforestry in Indonesia contained from 46 to 89 t C/ha, and simple agroforestry with intensive tree crops in Indonesia had a carbon stock of 37 t C/ha, while a similar system in Peru had 47 t C/ha.

## Use of woodfuel in developing countries

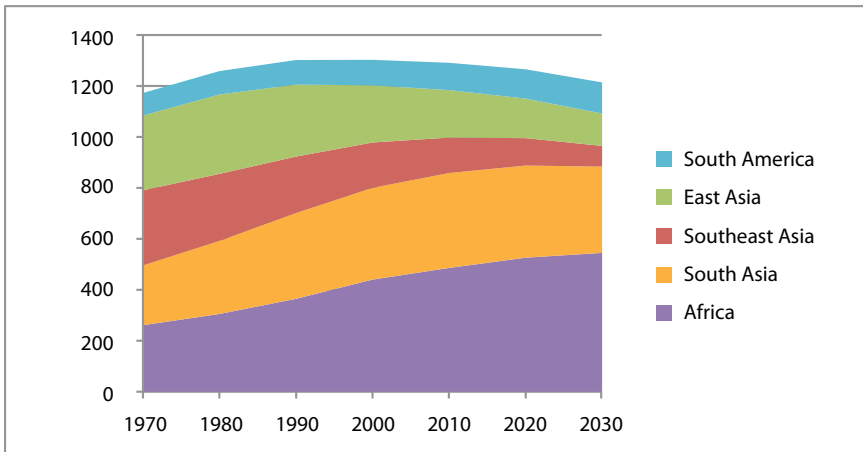
The total global production of wood in 2007 reached approximately 3600 million m<sup>3</sup>, of which 1900 million m<sup>3</sup> was used for woodfuel (FAO 2009b). This means that more than half of the total global wood removed from forests, and from areas outside forests, is used for energy production.

Asia accounts for nearly half of global fuel wood consumption, but consumption is declining (Figure 19.1), particularly in China, and in much of east and southeast Asia, where it has been falling since the 1980s. Africa has higher *per capita* fuel wood use than Asia, and consumption is still growing, although the rate of growth is slowing. In South America, where fuel wood is less important, overall consumption has been rising only slowly. In aggregate, the projections suggest that use of fuel wood in the developing world has just peaked, but that the use of fuel wood in the coming decades will decline slowly unless policies are put in place that limit its use. In contrast to fuel wood, aggregate charcoal consumption is still growing, and will continue to do so over the next few decades. The production of charcoal, though still low relative to fuel wood in most of Asia, accounts for a much higher share of woodfuel in Africa and South America. In Africa, the growth rate for aggregate consumption of fuel wood and charcoal is similar to the population growth rate.

The total amount of woodfuel, and the number of people who rely on woodfuel, are still very large. Biomass energy is expected to account for about three-quarters of total household energy consumed in Africa by 2030. In addition, estimates indicate that the number of people using fuel wood and other biomass fuels will rise by more than 40% to about 700 million. In Asia, even though consumption is declining, there may still be 1.7 billion users in 2030, and in Latin America 70 million (IEA 2006).

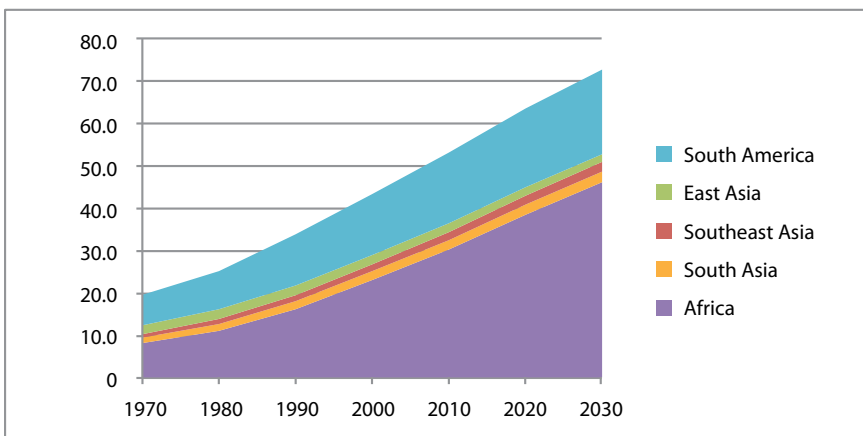
Although there are large variations between countries, *per capita* consumption of both fuel wood and charcoal tends to decrease as incomes increase. Urbanisation typically decreases fuel wood consumption and increases the use of charcoal, and *per capita* fuel wood consumption decreases as forest cover declines (Arnold *et al.* 2006).

The role that income plays in the choice of fuel has led to the 'energy ladder' hypothesis, which assumes a transition to modern fuels as income rises. Some analyses show that the income elasticity of fuel wood demand is negative, i.e., higher income means less use of fuel wood (considered an inferior good). Further, some studies find that fuel wood is a normal good for lower-income households, but an inferior good for higher-income households. Household studies also indicate that consumption of woodfuel will remain high for a long time to come, particularly in rural households (Arnold *et al.* 2006).



**Figure 19.1a. Projections of fuel wood consumption in developing regions (million m<sup>3</sup>)**

Source: Broadhead *et al.* (2001)



**Figure 19.1b. Projections of charcoal consumption in developing regions (million tonnes)**

Source: Broadhead *et al.* (2001)

In urban areas, fuel wood users are most likely to switch to charcoal. Charcoal is likely to overtake wood, in terms of the number of users and share of urban energy, as prices of wood increase relative to the prices of other fuels, as incomes rise and as cities become larger. Other 'transition' fuels are kerosene (paraffin) and coal. Gupta and Köhlin (2006) show that it is not only price that influences the transition from wood to modern fuels, but also convenience and the reliability of supplies. The set of policy options is thus broadened.

## Five policy options

This section discusses how demand- and supply-side interventions could be part of a national REDD+ strategy. We build on lessons from the ‘fuel wood trap’ discussion of the 1970s and 1980s (Munslow *et al.* 1988), and the experiences with many policy interventions over the past four decades.

The use of woodfuel stems from the demand for energy. Two policy interventions are of particular interest on the demand side: developing more efficient ways of cooking, and switching from woodfuel to other fuels. On the supply side, three policy options are relevant: developing more efficient charcoal kilns, measures to limit harvest rates to sustainable levels and developing plantations to lessen pressure on ‘natural’ forests.

Table 19.1 shows a simple assessment of effectiveness, efficiency and equity plus co-benefits (3Es+) of the five policy interventions. We have learned something about the effectiveness of these policies and some of their pitfalls during the last few decades, but less is known about the efficiency of individual measures and combinations of measures under various conditions.

**Table 19.1. Effectiveness, efficiency, equity and co-benefits of policy interventions**

Policy intervention	Effectiveness	Efficiency	Equity	Co-benefits
Cooking efficiency	Moderate	High	Hurts the poorest consumers if not subsidised	Better health, less local air pollution
Fuel substitution	High for clean energy, low for fossil fuels	Costly for clean energy, cheaper for fossil fuels	Hurts the poorest consumers if prices not differentiated	Better health, less local air pollution
Production efficiency	Moderate, must be combined with harvest control	High, if combined with harvest control	Hurts producers without capital	Less local air pollution
Controlling harvest	Low if centralised, higher if devolved	Low if centralised, higher if devolved	May benefit the rural poor, but elite capture possible	May benefit biodiversity in some areas
Plantations	High	Low, if harvest in indigenous forests is not controlled	Benefits land owners and producers with capital	Sequester carbon if planted on land with low biomass density

## Cooking more efficiently

Cooking in a pot placed on top of three stones around an open wood fire is not efficient. Most of the energy is lost and only 5% is transferred to the contents of the pot. Cooking efficiency can be improved by using dry fuel, enclosed burners or stoves, and pots with lids that fit well. With these and other measures, thermal efficiency can be increased to about 20% (Twidell and Weir 2006). If charcoal is used instead of wood, some energy is lost in pyrolysis, but thermal efficiency in cooking is better. Insulated stoves also improve efficiency. Traditional bucket stoves without insulation have efficiency rates of about 10%. Improved charcoal stoves with clay or ceramic insulation may have efficiency rates of up to 30%.

More efficient fuel wood and charcoal stoves may also have co-benefits. There are severe health problems related to the use of open fires, particularly indoors (Torres-Duque *et al.* 2008). These problems will be less with cookers that burn the wood more completely and release fumes outdoors.

Experience in many tropical countries during the last couple of decades shows that in most cases not more than 20% of consumers adopt improved charcoal stoves. The main reasons are that the stoves are too expensive, particularly for poorer urban households, that the insulation is easily broken and that charcoal is still fairly cheap. An important lesson learned from one of the successful stove projects, the Kenya Ceramic Jiko, is to make use of market forces and local artisans to increase adoption rates (Kammen 2000).

## Switching fuel

Woodfuel is a good substitute for fossil fuel if the wood is harvested from sustainable production systems. Similarly, renewable energy like hydro-, solar or wind power is a good substitute for woodfuel that is harvested unsustainably. In the analysis of demand we have seen that kerosene, coal and liquid propane gas are often the first substitutes for fuel wood and charcoal in many tropical cities. In most cases, this means substituting fossil fuels for unsustainably produced wood. Box 19.2 shows the net emission effect of such substitutions. Normally, such substitutions will contribute to increased emissions of GHGs when harvesting and transport of wood, as well as processing and distribution of fossil fuels, are accounted for. Thus, from a climate perspective, a move from even unsustainable woodfuel to fossil fuel cannot in general be recommended.

Switching to hydropower or other sources of renewable energy is more promising. However, many developing countries only produce a small proportion of their total electricity output from hydropower plants, windmills or solar panel parks. Most electricity is generated in power plants fuelled by

### Box 19.2. Efficiency and greenhouse gas emissions of cooking stoves

The efficiency of stoves that use fossil fuel varies considerably depending on the technology and how they are maintained. Average efficiencies of between 20% and 30% for coal, 35% and 45% for kerosene (paraffin), and 45% and 55% for liquid propane gas are assumed for typical applications (Bauen and Kaltschmitt 2001).

Even if renewably harvested, many biomass fuel cycles are not GHG neutral because they emit substantial products of incomplete combustion. To be GHG neutral, not only must biomass fuel cycles be based on renewable harvesting, but fuels must have close to 100% combustion efficiency, which most currently do not.

CO<sub>2</sub> equivalent emissions from different cooking options are given below (Bhattacharya and Abdul Salam 2002).

Cooking option	Efficiency value selected (%)	Emission factor value selected			Estimated CO <sub>2</sub> equivalent	
		CO <sub>2</sub> (kg/TJ)	CH <sub>4</sub> (kg/TJ)	N <sub>2</sub> O (kg/TJ)	g CO <sub>2</sub> -e <sup>1</sup> MJ <sup>-1</sup>	g CO <sub>2</sub> -e MJ <sup>-1</sup> <sub>useful</sub>
Kerosene	45	155 500	28.05	4.18	157.40	349.7
Liquid propane gas	55	106 900	21.11	1.88	107.90	196.2
Natural gas	55	90 402	20.65	1.84	91.40	166.2
Traditional stoves (wood)	11	–	519.60	3.74	12.10	109.7
Improved stoves (wood)	24	–	408.00	4.83	10.10	41.9
Traditional stoves (residues)	10.2	–	300.00	4.00	7.50	73.9
Traditional stoves (dung)	10.6	–	300.00	4.00	7.50	71.1
Improved stoves (dung)	19	–	300.00	4.00	7.50	39.7
Traditional stoves (charcoal)	19	–	253.60	1.00	5.60	29.7
Improved stoves (charcoal)	27	–	200.00	1.00	4.50	16.7
Improved stoves (residues)	21	–	131.80	4.00	4.00	19.1
Biogas stoves	55	–	57.80	5.20	2.80	5.1
Gasifier stoves	27	–	–	1.48	0.46	1.7

1 CO<sub>2</sub>-e is the carbon dioxide equivalent for a 100-year time horizon. TJ is a terajoule, equal to 1 trillion joules. MJ is a megajoule, equal to 1 million joules. And g CO<sub>2</sub>-e MJ<sup>-1</sup> means grams of CO<sub>2</sub> equivalents.



coal or oil. In many developing countries, the supply of electricity is also erratic and insufficient. If governments seek to substitute clean electricity for fossil fuel and unsustainably produced woodfuel, grids must be expanded to reach poor townships in cities and remote villages in rural districts. In cities, the cost per consumer of expanding grids should be cheap, whereas it will be more expensive in remote villages. How consumers are charged is also important. A progressive tariff, whereby households pay a very low, subsidised price for the first few kWh and a higher price thereafter,<sup>2</sup> applies in some countries and is a good compromise between equity and efficiency.

Substituting fossil fuel or clean electricity for fuel wood would particularly benefit women and girls who are in charge of cooking and fuelwood collection in many places, but it would also improve air quality for all members of the household. A subsidised supply of improved stoves or electricity would be important to poorer urban households.

### **Production efficiency**

Charcoal production in inexpensive earth mound kilns is most economical when the raw material, standing trees, is free or very cheap. But the energy loss is substantial. One tonne of charcoal contains 30 GJ (giga joules) of energy, and is usually derived from 6–12 tonnes of air-dry wood, i.e., between 90 and 180 GJ original energy content (Antal and Grønli 2003). Several other types of kilns, such as mud, brick and steel kilns, are more efficient. The technologies for these kilns are simple and would be easily transferrable if the economics were favourable. If producers have to pay stumpage,<sup>3</sup> they may be motivated to use more efficient technology because their raw material will no longer be free. The government could support training in more efficient technology. However, introducing more efficient kilns and training people to use them must be preceded by measures to control harvesting, otherwise the cost of training will be wasted.

Improved charcoal kilns may yield more, as well as producing commercially valuable byproducts. However, there has been little adoption in pilot schemes, mainly due to: high capital investment and maintenance costs; lack of specific returns from the market for byproducts; high cost of transport of metal kilns from one place to another when trees get scarce; time taken to ferry wood from different parts of the forest to the kiln; and lack of spare parts, maintenance skills and affordable and reliable credit facilities for capital investment.

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<sup>2</sup> Owners of air-conditioned buildings should pay a high price for electricity such that proper insulation becomes economical.

<sup>3</sup> A fee charged by owners for the right to harvest trees.

Substantial volumes of woodfuel are generated as forests and woodlands are cleared for agriculture. This mainly contributes to the energy supply in rural areas, particularly in the forest fringe where deforestation is most intensive. In many cases, clearing takes place so far from the market that much of the wood, particularly large trunks, is burned on the spot rather than taken away as fuel wood for cooking or other household needs. Producing charcoal from some of the logs takes care of some wood left after clearing. Constructing roads would make transporting woodfuel to market easier, but it would also make transporting agricultural produce easier and thus stimulate deforestation, so it might have an overall negative impact in terms of GHG emissions.

### **Controlling harvesting**

Several attempts have been made to control harvesting in indigenous forests and woodlands, such as issuing felling licences and controlling transport. For example, in Uganda a sustainable charcoal production and licensing system was piloted in major charcoal producing areas (Kalumiana and Kisakye 2001). Roadblocks to control charcoal transport to major African cities are common. Some states in Asia have been able to implement these kinds of measures effectively, but most attempts have failed. Loggers may buy one licence, but use it repeatedly. Others operate without a licence as they are unlikely to get caught. Transporters find routes to town that are not controlled, or they drive at night. Others bribe guards or forest officers. The authorities find it is not always worth putting in place costly control measures to regulate the harvest of low-value products like fuel wood and charcoal (Hofstad 2008).

A promising option seems to be to devolve responsibility for trees and forests (Cooke *et al.* 2008), for example, through some form of community forest management (see Chapter 16). If local communities or individual farmers owned trees, they might find it profitable to control harvests and charge stumpage fees. Fees could be in the form of a share of the final product, or a fee per unit output.

For many rural households, fuel wood or charcoal is a cash 'crop' that supplements the meagre income they otherwise earn. Transferring property rights of trees to local communities, individuals or farmers would increase their income, although elites could capture some benefits if rights were communal rather than individual. In the case of individual ownership, land grabbing by better-off people may threaten equity. However, if the raw material for woodfuel becomes more expensive, some of the costs would certainly be rolled over to urban consumers. Since poor households depend more on woodfuel than better-off households, more expensive fuel wood and charcoal would hit the poorer harder.

Licensing and quota systems for harvesting fuel wood and transporting woodfuel open up possibilities for corruption. Policy makers, therefore, should consider the risk of corruption and that elites could capture benefits when designing systems to regulate harvests in indigenous forests and woodlands (Larsen *et al.* 2000). Further, forestry personnel may often be excluded from processes for issuing licences and collecting revenue, as these may be handled by finance departments. In these cases, there would be no monitoring of harvests and available stocks, as the finance departments do not carry out such assessments.

## Plantations

The final policy option – plantations of fast-growing species – has been attempted in various locations. A number of large-scale plantations were established during the 1980s and 1990s to increase the supply of woodfuel. Many peri-urban plantations were established in the South (Sargent and Bass 1992; Evans and Turnbull 2004). Some have produced poles and wood for construction reasonably profitably, but hardly any have successfully supplied fuel wood or charcoal to urban consumers. As long as *de facto* open access forests and woodlands supply cheaper and better woodfuel, consumers will not shift to wood grown in plantations. For this policy to work, it has to be combined with measures that make woodfuel from indigenous forests less accessible and more expensive. This will happen either when the resource base becomes exhausted, or when harvests are controlled effectively. If REDD+ is the objective, then the latter option is preferable (Yao and Bae 2008).

However, in some places plantations are becoming more important as a source of woodfuels for commercial use. A study in Ethiopia demonstrated that fuelwood, for personal or commercial use, was the primary reason why 15% and 21% of respondents, respectively, planted trees (Arnold *et al.* 2006). In spite of the limited success of fuelwood from plantation forests, there is an unexploited potential for fuelwood as a byproduct from the management of on-farm trees and shrubs mainly used for other purposes. This is a relatively low-input tree crop that could be promoted through interventions favouring multipurpose woody species and management practices. A study from Orissa, India, also shows that community plantations can decrease the pressure on open-access natural forests (Köhlin and Parks 2001).

Many wood industries – logging companies, sawmills, veneer and panel factories – in many parts of the tropics waste huge volumes of wood that could provide raw material for bioenergy. If the prices of logs and fuel wood were higher, then better use of raw material and waste products might follow.

## Lessons learned and conclusions

There are clear lessons to be learned from decades of policy interventions in the forest–energy system. First, introducing maximum prices on woodfuels consumed in urban areas leads to high demand, low supply, queues and black markets. Second, establishing large, forest plantations to supply fuel wood is rarely effective. Third, control measures along transport routes from forest to city are rarely effective and often lead to corruption. Fourth, new technologies for producing charcoal or the combustion of woodfuel are not readily adopted unless they are extremely cheap, and unless measures to make wood from indigenous forests relatively more expensive are also introduced.

Several policies could reduce forest and woodland degradation from unsustainable harvesting of woodfuel, but policies that combine various measures are likely to be the most successful. On the demand side, policies could aim to accelerate substitution of ‘clean’ electricity for fuel wood and charcoal. These could be combined with aggressive marketing and subsidies for improved domestic charcoal stoves. However, the latter may lower the price of charcoal and increase demand, thereby dampening the impact.

Supply-side policies could take the form of community development projects in woodfuel supply zones, including the introduction of subsidised, efficient charcoal kilns. These policies would, however, have little effect if they were not combined with compulsory stumpage fees for indigenous trees. The latter requires a transfer of ownership to local communities or farmers, and it may still be necessary to control harvesting centrally to avoid overexploitation in high-demand areas. There is no substitute for better control of harvesting. Open-access forests and woodlands will be overexploited if harvesting is profitable. If payment of stumpage fees becomes common practice and those who harvest wood have to make better use of it to make a profit, then the private sector may find that plantations for fuel wood become a lucrative investment. Measures to encourage better use of harvested timber or trees felled to provide woodfuel would also contribute to REDD+.