Food and Agriculture Organization of the United Nations

Sustainable woodfuel for food security

A smart choice: green, renewable and affordable

Working paper

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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1. INTRODUCTION: FORESTS, TREES, WOODFUEL AND FOOD SECURITY

Forests cover one-third of the Earth's land surface. It is estimated that over one-third of the world's population depends on forest goods and services for the direct provision of food, woodfuel, building materials, medicines, employment and cash income.

Forests and trees outside forests, including tree-based agricultural systems, contribute to the four dimensions of food security (Box 1) in multiple ways (Table 1). Food from forests and trees (fruits, vegetables, nuts, mushrooms, fodder and

Box 1 **Definitions and key terms**

Food security is a state where all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Nutrition security is integral to the concept of food security (FAO, 2011a).

The four pillars of food security are **availability, access, utilization** and **stability**. Availability is achieved if there is adequate food ready for people's needs. Access is ensured when all households and all individuals within those households have sufficient resources to obtain appropriate foods (through production, purchase or donation) for a nutritious diet. Adequate utilization refers to the ability of the human body to ingest and metabolize food. Stability refers to the temporal determinant of food and nutritional security and affects availability, access and utilization. Chronic food and nutrition insecurity (the inability to meet food needs on an ongoing basis) is distinguished from transitory food and nutrition insecurity (e.g. due to natural and human-made disasters) (Gross *et al.*, 2000).

Woodfuel is defined as all types of fuels originating directly or indirectly from woody biomass. The main types of woodfuel in less-developed regions of the world are fuelwood and charcoal. Fuelwood is woodfuel in which the original composition of the wood is preserved; it includes wood in its natural state and residues from wood-processing industries. Charcoal is the solid residue derived from the carbonization, distillation, pyrolysis and torrefaction of wood (FAO, 2004).

Forest is defined as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use (FAO, 2015).

Deforestation is defined as the conversion of forest to other land use or the permanent reduction of the tree canopy cover below the minimum 10 percent threshold (FAO, 2015).

Forest degradation is the reduction of the capacity of a forest to provide goods and services (FAO, 2015).

Tree-based agricultural systems (also known as agroforestry systems) are defined by tree cover on agricultural land of more than 10 percent. They can include trees on farms, home gardens, intercropping, fallows, woodlots and plantations (Zomer *et al.*, 2014).

Table 1. Four dimensions of food security and their links to forestry and trees outside forests

Food security dimensions	Definition	Applicable level	Examples of linkages to forestry	Facts and figures
Food availability	Available food in total = production + imports + aid – exports – waste	National	Availability of edible non-wood forest products (NWFPs) Support to agricultural and fishery production through forest ecosystem services	Edible NWFPs account for 16.5 kcal/person/day globally As many as 600 tree species fix atmospheric nitrogen, improving soil fertility Shelterbelts have resulted in increases in grain production ranging from 30 to 200% in various countries 75% of the tree species of tropical Africa are used as browse or fodder trees
Food access	Economic, physical, social and legal access to food	Households and individuals	Increased household income from wood industries, wood and NWFPs	Global annual income from roundwood, sawnwood, panels, pulp and paper: US$600 billion Informal-sector annual income from fuelwood, charcoal and recorded NWFPs: US$124 billion Forest employment: nearly 54 million people (full-time equivalent) Forest owners: 30 million people
Food utilization	Physical ability to obtain sufficient nutritional intake and nutrient absorption	Individuals	Woodfuel for cooking and sterilizing water Provision of clean water for drinking and cooking Provision of protein and micronutrients	2.4 billion people (one-third of the world's population) cook with wood In Africa, over 60% of the population relies on woodfuel for cooking About 765 million people use wood energy to sterilize water
Food stability	Availability, access and utilization at all times without risk	All levels	Safety net in times of need Climate change mitigation and adaptation through sustainable forest management Protection of ecosystem services for sustainable food production	Forests have the potential to absorb about 10% of global carbon emissions, if managed sustainably Forested watersheds and wetlands supply 75% of the world's accessible fresh water for domestic, agricultural, industrial and ecological needs

Sources: Jin and Reeb, 2014; FAO, 2008, 2014; Aju, 2014

forage, bushmeat, insects, fish) contributes regularly to rural and urban diets and serves as a safety net in periods of food scarcity (Kiptot *et al.*, 2014; FAO, 2013). Wild plants, animals and edible insects from forests provide important nutrients and are often the main source of protein for people living in or near forests. Forests generate income for local people and provide essential ecosystem services that support agriculture by regulating water flows, stabilizing soils, maintaining soil fertility, regulating the climate and providing habitat for wild pollinators and predators of agricultural pests.

One of the most important contributions of forests to food security is the provision of woodfuel. For instance, cooking is the main way to ensure food utilization through high nutrient absorption from food, and globally 2.4 billion people use woodfuel for cooking (Table 2). Woodfuel is equally important for boiling and sterilizing water, and is often the only available means that forest-dependent communities have to ensure safe water for drinking and food processing. Woodfuel is also used in food preservation (e.g. smoking, drying), which extends the supply of food into non-productive periods.

Depletion or degradation of forest resources and trees outside forests puts at risk the multiple benefits that forests and trees provide for people's food security and nutrition. Between 2010 and 2015 an annual loss of forest cover of 7.6 million hectares, partially offset by an annual gain of 4.3 million hectares, resulted in a net annual decrease in forest area of 3.3 million hectares worldwide (FAO, 2015). In many areas of the world with relatively high forest cover (Figure 1), consumption of woodfuel also tends to be high (Figure 2).

About 795 million people are undernourished globally (FAO, IFAD and WFP, 2015). Limited availability of, and access to, woodfuel could exacerbate hunger and poverty by challenging the primary energy source for various purposes including cooking and sterilizing water. Deforestation and forest degradation imply the direct loss of nutritious forest food and income-generation opportunities (among many others), and thus also directly affect food security.

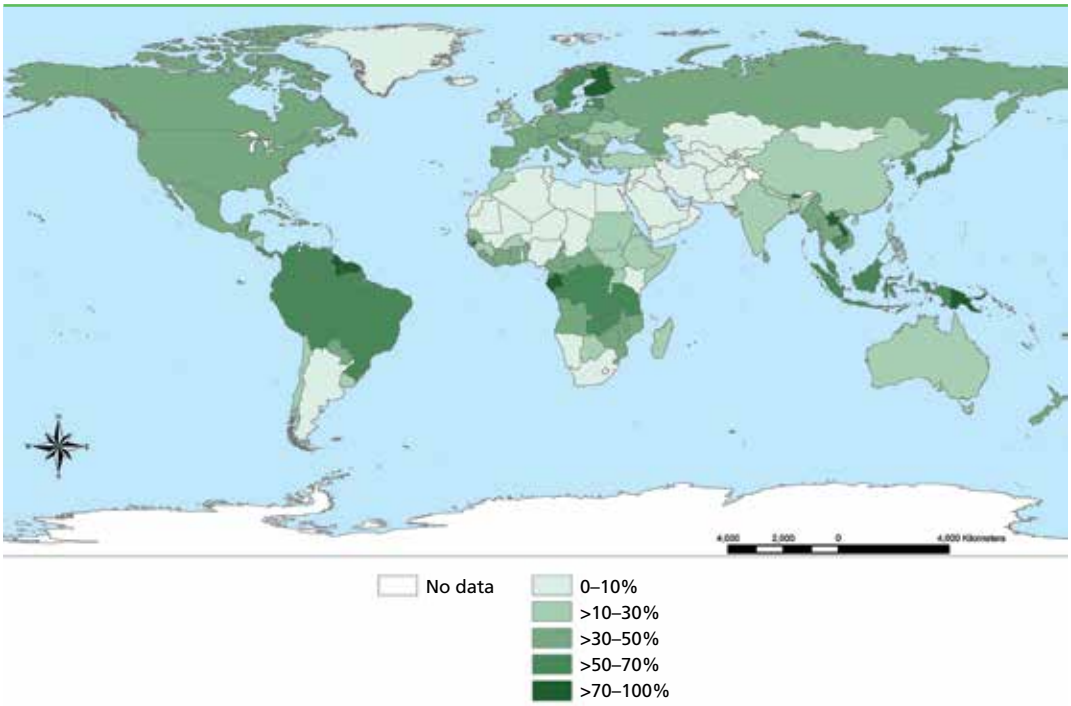
Woodfuel represents over 50 percent of the world's total wood production. One-third of woodfuel is harvested unsustainably (Bailis *et al*., 2015), generally

Table 2. Proportion of households cooking with woodfuel in 2011, by region and fuel type

Region	Share of households where wood is the main fuel used for cooking (%)			Estimated population using woodfuel for cooking ('000)		
	Fuelwood	Charcoal	Woodfuel	Fuelwood	Charcoal	Woodfuel
Africa	53	10	63	555 098	104 535	659 632
Asia and Oceania	37	1	38	1 571 223	59 034	1 630 257
Europe	3	0	3	19 001	156	19 157
North America	0	0	0	0	0	0
Latin America and the Caribbean	15	1	16	89 569	5 383	94 952
World	**32**	**2**	**34**	**2 234 890**	**169 108**	**2 403 998**

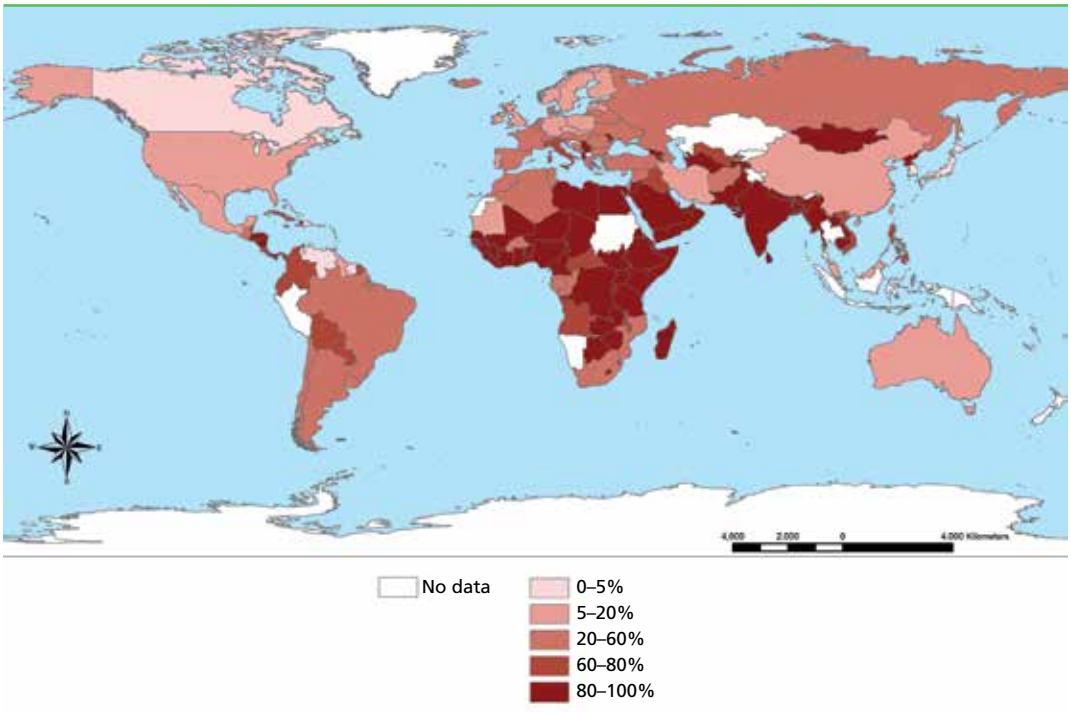
Source: FAO, 2014

FIGURE 1. World forest area as percentage of total land area, 2015



Source: FAO, 2015

FIGURE 2. Proportion of woodfuel in wood removals, 2011



Source: FAO, 2015

Box 2

Changing views about woodfuel and forest resource degradation

Over the past 40 years the prevailing view on woodfuel has fluctuated dramatically. In the 1970s, it was widely noted that woodfuel was the predominant household fuel for most of the developing world. With increasing populations, a growing gap between supply and demand was envisioned, expected to result in massive deforestation and declining welfare for woodfuel-dependent households. By the late 1980s, however, it became evident that the predicted woodfuel crisis would not come to pass. New household-level research indicated that woodfuel generally came from easily regenerating twigs and woody scrub, that scarcity of woodfuel could be driven by labour shortages even when forest resources were abundant, and that households responded rationally to economic scarcity of woodfuel both by conserving fuelwood and by switching to substitutes. The view that prevailed in the 1990s was that woodfuel use was not a major cause of deforestation and that woodfuel scarcity was not a big problem for most households. Today, woodfuel is still the predominant fuel for rural households in much of Africa and South Asia, and it is now recognized that in some circumstances woodfuel scarcity can have very adverse consequences for household welfare.

Source: Cooke St Clair, 2011

as a result of unregulated forest access, and contributes to forest degradation. However, contrary to popular belief, it is not a main cause of deforestation (Box 2). The main driver of deforestation is conversion to agriculture, accounting for almost 80 percent of the world's forest loss (FAO, 2016a), while weak governance, lack of tenure rights for local communities and poverty are underlying drivers which can lead to unsustainable exploitation of forest resources.

Through improved management, woodfuel production and harvesting systems can be made sustainable. In addition, with appropriate and efficient stove systems in place, sustainable woodfuel use can contribute significantly to food security for the more than 2 billion people who depend on it as their primary source of energy for cooking.

This paper explores the links between sustainable woodfuel and food security, primarily in the context of household use in developing countries, and examines the opportunities for strengthening these links at all stages from production through safe and efficient use.

2. WOOD ENERGY USE AND FOOD SECURITY

Woodfuel is an ancient energy source and is likely to be used by many, in both rural and urban areas, for decades to come (Nakada, Saygin and Gielen, 2014; OECD/IEA, 2015). This is especially the case in Africa, where charcoal use in urban centres is increasing and alternative energies are not yet sufficiently available (Mwampamba *et al.*, 2013). Global wood charcoal production trebled between 1964 and 2014, increasing from 17.3 to 53.1 million tonnes. Of the current global production, 61 percent occurs in Africa, primarily to satisfy cooking-fuel demand from urban and peri-urban households (Doggart and Meshack, 2017).

Woodfuel dependence varies largely among regions of the world and between urban and rural areas, reflecting different levels of development and the availability of alternative energy sources. In most regions, woodfuel dependence has declined or remained steady over time. The exception is sub-Saharan Africa, where per capita consumption is two to three

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Charcoal for sale at a market in the Democratic Republic of the Congo

times higher than in any other region and total consumption continues to increase (Figure 3) (FAO, 2017a).

According to a World Health Organization (WHO) survey of 128 low- and medium-income countries, over 75 percent of rural households and around 20 percent of urban households depend primarily on woodfuel for cooking (WHO, 2016a). Woodfuel is of particular importance to the poorest people, for whom it is often the cheapest, most readily available and most easily accessible source of fuel.

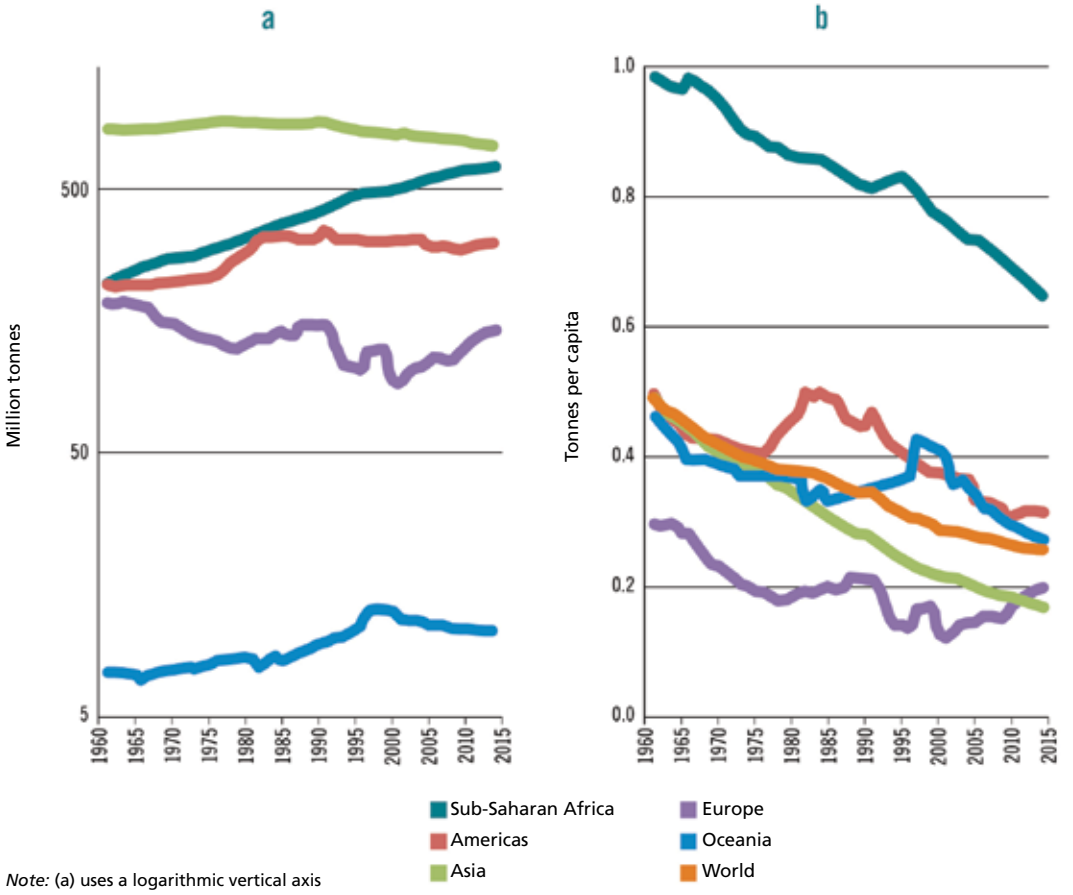
Asia has the highest level of total woodfuel use, while Africa has the highest per capita demand (0.57 m^3 per person per year). The countries with the highest levels of woodfuel use are India, China, Brazil, Ethiopia and the Democratic Republic of the Congo (FAO, 2016d).

WOODFUEL IN HOUSEHOLD ENERGY MIXES

Whereas woodfuel used to be considered the bottom of the household energy ladder, today it is recognized that households use different fuels for different purposes and that woodfuel is likely to be part of this energy mix at the global level (Table 3). The use of multiple energy sources for multiple purposes ("stacking") is not a short transition phase but can last for decades, as shown in Mexico and China (Masera *et al.*, 2015). Charcoal use is more common in middle-income households in urban areas than in poor rural areas, preferred to fuelwood because of its higher energy content, ease of storage and transportation and lower smoke emissions.

Household energy choice depends not only on income and available energy

FIGURE 3. Total (a) and per capita (b) woodfuel consumption trends by region



Note: (a) uses a logarithmic vertical axis

Source: FAO, 2017a

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Despite the availability of alternative energy sources, this woman in Cobán, Guatemala, prefers to use fuelwood to give her tortillas a particular taste

WOODFUEL USE FOR COOKING AND FOOD PRESERVATION

While one-third of the world's people use woodfuel for cooking, reliance is highest in Africa (63 percent) and Asia and Oceania (38 percent), followed by Latin America and the Caribbean (15 percent) (FAO, 2014). These are the same regions where 98 percent of the world's 795 million undernourished people live (FAO, IFAD and WFP, 2015). Woodfuel is less frequently used for cooking in Europe (3 percent of energy use) and in North America (less than 1 percent) (FAO, 2016d).

In addition to household use, woodfuel is also used for commercial food preparation, such as in schools (see Box 3), restaurants, street food and food-related small-scale industries such as agro-processing (tea drying) and food preservation (fish smoking).

sources, but also on habits, taste, culture, customs, experiences, skills and external conditions. When alternative energy sources such as liquefied petroleum gas (LPG) and electricity are adopted, they are often used for reheating, quick and ready-made meals, while woodfuel often remains the preferred option for cooking traditional foods that require long preparation times (Masera *et al.*, 2015; Hiemstra-Van der Horst and Hovorka, 2008).

COOKING AND FOOD SECURITY

Household and commercial cooking directly contributes to the utilization dimension of food security, making food more digestible. Cooking food enhances the uptake of nutrients. Many foods with high nutritional value, such as beans and cereals – which are especially important in the diets of people who cannot afford animal protein – require long cooking times.

Table 3. Primary cooking fuel per region (%)

Region[a]	Electricity	Gas	Kerosene	Coal	Biomass	Other
Africa	6	9	6	<1	77	2
Americas	2	80	<1	<1	17	1
Eastern Mediterranean	<1	64	<1	<1	34	<1
Europe	13	70	<1	<1	12	<1
Southeast Asia	<1	32	3	2	62	<1
Western Pacific	4	49	<1	4	43	<1

Source: WHO, 2016a, citing data from the WHO household energy database (www.who.int/indoorair/health_impacts/he_database), containing information from more than 800 surveys collected from 161 countries between 1970 and 2014

[a] Following WHO classification of regions

Box 3

Improving schoolchildren's food security in India: improved cooking stoves, plantations and gardens

Children in government schools in Karnataka, India receive cooked meals to improve their nutritional status. Fuelwood is the main cooking fuel used to prepare these meals, as the supply of LPG is unreliable. Gopal and Nagaraju (2013) described an integrated project initiated to combat resource overexploitation and high prices by providing improved biomass cooking stoves and raising a woodfuel plantation and a bio-intensive school garden. The project provided a value-chain solution to supply, contributed to the sustainable supply of woodfuel for the local community and helped to increase awareness among schoolchildren about natural resource management and nutrition.

In addition, cooking increases the bio-availability of certain micronutrients in food, such as beta-carotene (in such foods as tomatoes, carrots and sweet potatoes) and lycopene (an anti-oxidant found in tomatoes), and allows iron and other minerals to be better absorbed by the body. Smoking and drying improve availability of food by preserving it and prolonging its shelf life beyond the growing season. Cooking and reheating food also increases food safety by eliminating dangerous micro-organisms and removing toxic elements.

Untreated drinking-water may contain parasites and pathogens that cause diarrhoea, typhoid or dysentery. An estimated 663 million people globally in 2015 had no access to clean, safe drinking-water and had to source water from unprotected wells, springs and surface water (UNICEF and WHO, 2015). Boiling is the most common method for treating drinking-water, used by around 20 percent of people in developing countries (UNICEF and WHO, 2011). An estimated 1.38 billion people in Africa, Asia, Latin America and the Caribbean and Oceania treat drinking-water by boiling it, and about 765 million people (10.9 percent of the global population) use woodfuel for this purpose (FAO, 2014). Clean water is also needed to wash food, for general household hygiene and for treating wounds (WHO, 2006).

Women cook food in a village market in Kyrgyzstan; cooking increases nutrient availability and food safety

3. WOODFUEL PRODUCTION AND TRADE, AND THEIR LINKS TO FOOD SECURITY

WOODFUEL SOURCING AND WOOD PRODUCTION SYSTEMS

Forests and trees outside forests are part of wider landscapes with various productive and ecological functions such as production of crops and other natural products, conservation and carbon sequestration, as well as biofuel production. Woodfuel can be produced from a variety of sources along the forest–tree landscape continuum from (managed) forests, to agroforestry and shifting cultivation systems, to trees in public parks and home gardens.

Biofuel production and the other functions of the landscape carry potential trade-offs, but can also be complementary. Agroforestry systems, for example, provide food and fuelwood while also indirectly contributing to food security by offering fodder and ecosystem services (Arnold, Köhlin and Persson, 2006; Njenga *et al.*, 2013). Agroforestry has been shown to improve access to fuelwood on farms and to reduce the need to purchase fuelwood in rural areas. Women engaged in agroforestry in Kenya reported spending less time collecting fuelwood and more time on income-generating activities and agriculture (Thorlakson and Neufeldt, 2012). Women and children often collect woodfuel simultaneously while gathering edible non-wood forest products such as nuts, fruits and leaves (Adnan *et al.*, 2012; Ingram, 2014; Majule *et al.*, 2012) (Box 4).

In urban areas of developing countries, woodfuel demand is often met from surplus wood when forest lands are converted to farmland. Smaller quantities of wood are sourced from plantations or waste from timber operations (Chidumayo and Gumbo, 2013; Schure *et al.*, 2012). However, even woodfuel for urban use is sometimes directly harvested from forests or agroforestry systems, particularly when demand and market prices are high. For instance, fuelwood collection for household use recommenced in peri-urban areas of Nigeria in 2008 following sharp food price increases, as a way to reduce household expenditures (Maconachie, Tanko and Zakariya, 2009).

SUSTAINABILITY OF WOODFUEL PRODUCTION

As explained in Chapter 1, woodfuel collection is rarely a direct cause of deforestation. In Africa, however, unsustainable fuelwood collection and

Box 4 **Fuel, food and more: *Ziziphus spina-christi*, Ethiopia**

In Shewa, Ethiopia, Christ's thorn jujube (*Ziziphus spina-christi)*, an evergreen tree, is valued by local people and integrated in dryland agroforestry systems. The wood is popular for fuelwood, charcoal making and timber. An estimated 20 to 30 kg of fuelwood can be collected annually after pruning. The leaves and fruits are used as livestock fodder, contributing to provision of animal-derived protein for people in these marginal, semi-arid lands (Feyssa *et al.*, 2011).

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Unsustainable woodfuel harvesting on a local scale can mean that collectors – usually women – have to walk longer distances to find it (Democratic Republic of the Congo)

charcoal production – favoured by open access with a lack of clear and secure forest and tree tenure – do constitute the main cause of forest degradation, accounting for as much as half of it (Kissinger, Herold and de Sy, 2012). Woodfuel also contributes to forest degradation in other developing regions, but to a far lesser extent. It is estimated that 27 to 34 percent of woodfuel harvesting in tropical regions is unsustainable, with around 275 million people living in "woodfuel depletion hotspots" where more than 50 percent of woodfuel harvesting is unsustainable (Bailis *et al*., 2015). Chidumayo and Gumbo (2013) estimate that in Africa, charcoal accounted for the loss of almost 3 million hectares of forest cover in 2009.

Although the availability of woodfuel is found to be mostly sufficient at global and national scales (Smeets *et al.*, 2007; Openshaw, 2011), unsustainable woodfuel harvesting causes pressures on a local scale. In rural areas, such pressures are associated with more labour needed to collect fuelwood for subsistence use, putting a burden on women and children who are mostly responsible for this task (Burke and Dundas, 2015; Sunderland *et al.*, 2014). Urban residents are confronted with increasing market prices of fuelwood and charcoal and resource depletion of peri-urban tree sources. High urban demand for woodfuel creates pressure on peri-urban forest and tree resources (Dubiez *et al.*, 2012), contributing to land degradation, which can have negative impact on food availability as these lands are also needed for agricultural production to feed urban populations.

SUSTAINABLE WOODFUEL AS PART OF FOOD PRODUCTION SYSTEMS

Sustainable woodfuel production depends on sustainable management practices that ensure regrowth or regeneration that is at least equal to the level of extraction. Especially in areas where slash-and-burn agriculture is common, and harvest pressure leads to shortened rotation periods and associated degradation, assisted natural regeneration (enrichment planting) can

promote regeneration of specific tree species (Dubiez *et al.*, 2012). The natural regeneration of tree species can be in synergy with crop production cycles, particularly if tree species are targeted that are popular for food or fuel uses (Schure *et al.*, 2012).

Plantations can provide woodfuel, possibly in combination with food production. Village and household plantations can serve as a buffer for protected areas while meeting needs for timber, forest foods and fuel (Schure *et al.*, 2012). For example, near Kinshasa, the Democratic Republic of the Congo, *Acacia auriculiformis* plantations raised specifically for woodfuel production, maintained by farmers in an agroforestry system, provide wood resources for year-round charcoal production combined with staple agricultural crops (Bisiaux, Peltier and Muliele, 2009) (Box 5).

The use of "fertilizer trees" (nitrogen-fixing plants) contributes to soil fertility and higher crop yields, which is especially important in regions of the world where external inputs are less accessible and soil nutrient depletion is a concern. For instance, using fertilizer trees such as *Gliricidia sepium, Leucaena* spp., *Tephrosia* spp. and some *Acacia* spp. has helped to double maize yields in some countries in eastern and southern Africa while providing fuelwood and fodder, reducing erosion and sequestering carbon (Akinnifesi *et al.*, 2011).

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These women of Moree, Ghana, who earn their living by processing and selling fish, cultivate a woodlot to source wood for their smoking ovens and diversify their incomes

Box 5

Synergies between woodfuel and food crop production in an agroforestry system, the Democratic Republic of the Congo

One of the few plantations for urban woodfuel supply in the Democratic Republic of the Congo is the 8 000-ha *Acacia auriculiformis* Mampu plantation. The reforestation scheme, initiated in 1995, is divided into 25-ha plots shared by 320 farming families. On each plot tree plantation is combined with agroforestry. Charcoal production from the plantation ranges from 8 000 to 12 000 tonnes per year, supplying the capital city of Kinshasa. The agroforestry system also produces 10 000 tonnes of cassava, 1 200 tonnes of maize and 6 tonnes of honey per year.

Since 2009, the farmers have official land titles, and a farmers' union manages the plots independently of the original project. The success of the project has made it a model for other reforestation and agricultural initiatives in the area. Lessons learned include the recognition that land rights need to be taken into account together with testing and application of diverse income-generating activities and production processes, for support not only to urban energy supply but to meaningful local development. Based on the Mampu experience, a new farmers' plantation has been developed on the Batéké Plateau called Ntsio, where more tree types (acacia, pines, eucalyptus) are integrated to provide woodfuel, timber and soil fertility, to demarcate land, to avoid fires and to control erosion (Bisiaux *et al.*, 2013; Boulogne *et al.*, 2013; Iragi, 2016).

WOODFUEL TRADE AND FOOD SECURITY

Commercial woodfuel production often gains importance in livelihood strategies when there is high urban demand and when woodfuel production is complementary rather than competing with agricultural crop production (as shown above in Box 5). Woodfuel production generated US$33 billion of income in 2011 (FAO, 2014). An estimated 880 million people worldwide spend part of their time collecting fuelwood or producing charcoal.

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Fuelwood for sale in a wood market in Cambodia: income from woodfuel sales pays for food and other basic needs and provides capital to invest in agriculture or other livelihood strategies

© J. Schure

Charcoal generates revenue for women, who often dominate in its marketing, although its production is mainly carried out by men (Democratic Republic of the Congo)

Commercial fuelwood and charcoal activities to supply urban centres involve over 40 million people, representing 1.2 percent of the global workforce (FAO, 2014).

Woodfuel commercialization can contribute to household income diversification. In northern Ghana, charcoal making and fuelwood collection were among the non-farm activities that positively influenced household food security (Owusu, Abdulai and Abdul-Rahman, 2011). A comparative study in developing countries found that incomes from products collected in forests and other natural, non-cultivated environments (termed environmental income) represented 28 percent of total household income for (selected) rural households, with woodfuel (fuelwood [31.2 percent] and charcoal [4.0 percent] together) the most dominant product, accounting for 35.2 percent of environmental income and representing about 7.8 percent of total household income (Angelsen *et al.*, 2014).

Income from woodfuel sales pays for food and other basic needs and provides capital to invest in agricultural activities (Schure *et al.*, 2014). Fuelwood trade can act as a safety net for households during periods of food shortage, by providing cash to purchase food, as described by Koffi, Djoudi and Gautier (2017) in rural Burkina Faso. In Ethiopia, where many people are chronically food insecure, fuelwood and charcoal trade provide a coping strategy to generate income and purchase food in drought years (Endalew, Muche and Tadesse, 2015). In particular, charcoal generates revenue for women, who often dominate in its marketing and retailing (Ingram *et al.*, 2014; Zulu and Richardson, 2013; Sunderland *et al.*, 2014). However, charcoal production for commercialization is mainly carried out by men (Ingram *et al.*, 2014), and in some cases it has diverted labour away from agriculture, leaving women with more work (Zulu and Richardson, 2013).

4. CHALLENGES AND OPPORTUNITIES FOR SUSTAINABLE WOODFUEL PRODUCTION AND USE

CHALLENGES

Potential woodfuel shortage

In general, woodfuel supply is sufficient to meet the demand (see Box 2, p. 5). However, woodfuel scarcity may occur on a local scale, brought about by a lack of sustainable management and regulation of wood resources, informal woodfuel trade dynamics and poorly defined tenure rights. Woodfuel may also be too costly for certain users to buy. In a 2008 survey of rural households in the downstream zone of the Old Brahmaputra River in Bangladesh, 94 percent of households reported that they faced fuelwood scarcity, mostly for this reason (Akther, Miah and Koike, 2010).

Fuelwood shortage can have direct implications for food and nutritional security. In Malawi, for example, seasonal reductions in woodfuel availability have been associated with reduced intake of nutritious foods that require long cooking times, such as cereals and beans (Brouwer *et al.*, 1996; Brouwer, Hoorweg and Van Liere, 1997). Ndayambaje, Heijman and Mohren (2012) reported that in Rwanda, some households have coped with seasonal fuelwood shortages by reducing the number of meals and eating food without cooking.

Shortages can also affect urban areas, where woodfuel is usually supplied through markets. A ban on charcoal in Chad in December 2008, combined with a lack of alternative fuels, resulted in citizens of the capital, N'Djamena, burning their furniture and fruit-bearing trees (*IRIN News*, 2009). Usually, when wood supply near urban centres is insufficient, woodfuel is supplied from farther away, which results in higher woodfuel prices for urban households (Arnold *et al.*, 2003).

Shortage of woodfuel often arises during crises and conflicts, and in these situations it can endanger the food security of already vulnerable groups such as refugees and internally displaced people. WFP (2000) reported a number of examples of the woodfuel challenges faced by refugees:

- refugees in Bangladesh who were prohibited from collecting standing woodfuel resorted to burning maize cobs, selling part of their food aid or collecting woodfuel illegally;
- newly displaced women in Angola only had twigs and leaves to burn for cooking, which created a fire inadequate to boil drinking-water, posing a health risk;
- women in Tanzanian refugee camps had to travel great distances to collect fuelwood, spending on average two entire days a week in this pursuit.

In general, strategies used for coping with woodfuel shortage include reducing cooking times, extinguishing fires immediately after cooking, increasing the time spent collecting woodfuel, using any accessible substitutes (e.g. crop residues, leaves, rice husks and rice straw, twigs and cow dung), cooking meals that need less fuelwood, using better pots, lowering the fire grate, soaking beans and maize to reduce cooking times, and buying fuelwood from the market (Damte, Koch

and Mekonnen, 2012; Akther, Miah and Koike, 2010; Ngetich *et al.*, 2009; Mlambo and Huizing, 2004; Ndayambaje, Heijman and Mohren, 2012). Investing more labour in fuelwood collection is often a difficult coping measure, as it is especially burdensome for women and children, who are commonly responsible for this work, and the time spent collecting fuelwood cannot be spent on other activities such as agriculture or education (Chege, 1994; WHO, 2016a; Sidh and Basu, 2011).

Health risks of woodfuel use

Smoke is one of the greatest health risks of woodfuel, especially when it is used indoors. WHO estimates that 3.1 billion people, mostly poor and living in low- and middle-income countries, use polluting fuels such as biomass (wood, dung, crop residues and charcoal), coal and kerosene to cook and heat their homes using open fires and simple stoves (Stloukal *et al.*, 2013; WHO, 2016b).

Household air pollution is the single most important environmental health risk worldwide, with 4.3 million deaths each year from pulmonary diseases, strokes, lung cancer and ischaemic heart disease related to cooking with solid fuels including coal and biomass (WHO, 2016b). Household air pollution can also lead to blindness. Women and children in particular face high risks from exposure. Malnourished people and those with nutrient deficiencies are more prone to suffering from diseases induced by poor air quality (Stloukal *et al.*, 2013). Other health risks from woodfuel use, particularly for women and girls as the main users, include burns and injuries (WHO, 2016a).

In some cultures, the smoke from domestic fuel use is believed to have a benefit in repelling mosquitoes, which carry diseases such as malaria. However, while the burning of particular aromatic plants may have some efficacy in repelling mosquitoes, WHO (2008) found that the presence of cooking smoke has no effect on indoor abundance of African malaria vectors. In any case, under normal conditions of domestic fuel use, most cooking is done outside the peak biting times for malaria vectors.

Climate impacts of woodfuel use

Climate impacts from woodfuel use include CO_2 emissions from unsustainable wood harvesting and methane (CH_4) and black carbon (the most light-absorbing component of particulate matter) emitted during incomplete combustion. Estimates of woodfuel's contribution to global anthropogenic emissions range from 2 percent (Bailis *et al.*, 2015) to 7 percent (FAO, 2016d). Traditional bioenergy (which includes agricultural residues and dung in addition to fuelwood and charcoal) contributes 18 to 30 percent of global black carbon emissions (Masera *et al.*, 2015). Climate change affects all aspects of food security, with temperature increases predicted to have negative effects on the production of major crops (such as wheat, rice and maize) in tropical and temperate regions (Porter *et al.*, 2014). Shindell *et al.* (2012) projected that reducing global warming by 0.5 °C through decreased methane and black carbon emissions could increase annual crop yields by 30 to 135 million tonnes in 2030 and beyond.

Although combusting wood emits CO_2 into the atmosphere, woodfuel use is generally considered almost carbon neutral because it is assumed that regrowth of wood captures about the same amount of CO_2 from the atmosphere. Furthermore, it should not be assumed that woodfuel is always harvested from living trees that would accumulate more carbon if fewer of them were harvested for energy use. Woodfuel collectors always prefer dry wood and mostly focus on dead trees or branches. When woodfuel is produced from land that is being cleared for agriculture or is collected as dead wood, as harvesting or processing waste or from dead or dying trees, then a change in woodfuel demand is likely to have little or no impact on

emissions (FAO, 2016c). Residues from non-sustainable logging and land conversion, if not used as fuel, would simply be consumed in other ways or decompose by natural processes and would thus lead to the same amount of carbon emissions as burning. In other words, woodfuel's net emissions of carbon into the environment are close to zero (FAO, 1997).

Obviously, if woodfuels were not utilized, some alternative energy source would be required and used, and the usual fossil-fuel alternatives (coal, gas or oil products) would immediately result in a net increase in CO_2 emissions. Providing alternatives to woodfuel, such as LPG, piped natural gas and alcohol fuel (ethanol gel, particularly from sugar-producing countries), has often been proposed as an avenue for promoting rural development. However, the CO_2 impacts, economic costs and cultural difficulties (given deep-rooted cultural preferences and habits associated with woodfuel) associated with the transition to alternative fuels belie the attractiveness of this solution (FAO, 1997; Akpalu, Dasmani and Aglobitse, 2011).

OPPORTUNITIES

If managed sustainably, woodfuel can offer future benefits as a renewable and affordable energy source for both rural and urban areas. Practices for improving the sustainable use of woodfuel in line with food security objectives, particularly in rural areas, fall in the following three main categories.

Sustainable woodfuel production options

Sustainable woodfuel options can include dead wood, wood from dead or dying trees, and harvesting or processing waste. Woodfuel can also be produced sustainably through agroforestry, plantations, enrichment planting and managing fallows and degraded forests (Agyeman *et al.*, 2012; Dubiez *et al.*, 2012; Githiomi and

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Sustainable woodfuel management by a community forestry group in Nepal: a limited amount of fuelwood is harvested for sale to members at a nominal price, and the proceeds contribute to community improvement projects

Oduor, 2012). Planting for sustainable woodfuel production requires suitable tree species for the location with short rotation periods, selected based on local knowledge and practices and taking account of the needs and uses of forest products by local populations (Sizer *et al.*, 2005). These options are technically simple, well proven and documented. However, they require an enabling policy and legal environment (see Chapter 5).

Box 6

WHO guidelines for indoor fuel combustion

In 2014, WHO issued guidelines for indoor air quality related to household fuel combustion, specifying targets for emission rates for carbon monoxide and particulate matter from household fuels. The guidelines also provide good practice recommendations for securing health and climate co-benefits, for example through better ventilation and cooking technologies (WHO, 2014).

Improving fuel efficiency for resource conservation, climate impacts and air quality

Simple practical solutions exist for more efficient use of woodfuel. Fuel-saving practices include using efficient technology for combustion of wood and production of charcoal; using an appropriately sized pot with a fitting lid; protecting the stove from the wind; burning dry and small pieces of wood; and planning meals (soaking, tenderizing and preparing ingredients) to reduce cooking time (WFP, 2012; Practical Action, 2017).

In particular, improved cooking stoves can offer more complete combustion and more efficient energy use, with benefits including better household air quality and improved respiratory health (Box 6). In many countries their introduction may have a relatively high benefit-cost ratio and may be highly desirable from an economic perspective (FAO, 2016c). Basic improved fuel-efficient woodstoves can be easily built with local and readily available materials at almost no cost (Practical Action, 2017) (Table 4).

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Woman cooking on an improved smokeless oven in her home, Ghana

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Basic improved stoves can be made with locally available materials at almost no cost: displaced women in Western Darfur, the Sudan, learn how to make fuel-efficient stoves out of mud

Table 4. Improved cooking solutions

Level of improvement	Key features	Technologies
Basic	Small functional improvements in fuel efficiency over baseline technologies Typically artisanally produced	Legacy biomass and coal chimney stoves Basic efficient charcoal Basic efficient wood
Intermediate	Rocket-style designs (having a combustion chamber with an insulated vertical chimney) with a focus on highly improved fuel efficiency Include both portable and built-in models	Portable rocket stoves Fixed rocket chimney Highly improved (low CO_2) charcoal stoves
Advanced	Fan or natural-draft gasifiers with high fuel and combustion efficiency Often designed for pellet/briquette fuels	Natural-draft gasifier (top-loading updraft [TLUD] or side-loading) Fan gasifier/fan jet Combination TLUD and charcoal stoves

Source: Adapted from World Bank Group, AFREA and ESMAP, 2014

In some situations, improved stoves can also contribute to reduced greenhouse gas emissions. In an analysis based on data from 73 countries, Whiteman and Fornari (cited in FAO, 2016c) found that at the global level, switching to improved cooking stoves would have only a small impact on annual CO_2 emissions, reducing them by just under 0.5 percent of existing emissions. However, the potential emission reductions in Africa are more significant, i.e. about 1.5 to 3.0 percent of current CO_2 emissions.

Yet despite decades of projects, the use of cleaner cooking systems in developing countries is still low. Successful stove programmes require matching user requirements (economic and cultural), using technologies of proven efficiency and demonstrating the health and safety benefits to users (Urmee and Gyamfi, 2014). Effective distribution of improved cooking stoves depends on a combination of supportive business initiatives, locally appropriate innovations, awareness-raising campaigns, marketing, quality control, an enabling policy and regulatory environment and up-front financing or microcredit options to spread the costs of investment in new stoves (Bailis *et al.*, 2009; Lambe *et al.*, 2015). Given the cost implications, introducing improved stoves may be more feasible in urban areas or in countries with better economic conditions.

5. WAYS FORWARD AND RECOMMENDATIONS

HOW TO REALIZE THE FULL POTENTIAL OF WOODFUEL AND SUPPORT FOOD SECURITY: POLICY ASPECTS

Dependence on woodfuel as a primary cooking fuel prevails in developing regions of the world and affects vulnerable groups of people. Woodfuel, at all stages of its production, trade and use, is strongly linked to food security. Related policies need to combine supply-side and demand-side interventions while targeting the synergies between energy supply and food security and nutrition, in the context of climate change (Box 7). Spatial mapping tools such as the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) model (WISDOM, 2017) can help countries plan strategically to meet woodfuel demand sustainably. In addition,

Box 7

Integrated policy for forests, woodfuel and food security in the Republic of Korea

After decades of overharvesting, in the 1970s the Republic of Korea began to implement forest rehabilitation plans that included woodfuel production and a focus on food, nutrition and socio-economic benefits (FAO, 2016b). At that time fuelwood was the major energy source in rural areas. During the First National Forest Plan (1973–1978), 207 773 ha of fast-growing woodfuel forests were created. False acacia (*Robina pseudoacacia*) planted for woodfuel also contributed to over 70 percent of the country's honey production (Yoo *et al.*, 2014). The government promoted village-based communal reforestation projects, strengthened forest conservation laws by prohibiting unauthorized forest entry, limited forest resource extraction and improved fireplaces.

The fireplace improvement project introduced a smaller, simpler fireplace construction using mud that households could easily adopt to continue using woody and plant biomass for cooking. The fireplaces improved fuel efficiency by 30 percent, reducing the consumption of fuelwood. They also reduced indoor smoke and associated health risks, particularly for women as the main users of kitchen fireplaces. In the early 1970s the country had almost 6.8 million fuelwood-burning fireplaces, on average 2.6 per household. By 1976 all fireplaces were improved.

With socio-economic development, fuelwood use in cooking in the Republic of Korea has gradually been replaced by gas and coal. The fuelwood plantations developed through the reforestation effort are now managed on long rather than short rotation and are used for profitable timber production. Charcoal, however, is increasingly popular, especially in restaurants and outdoors for barbecues. To meet the demand (which has tripled since 1992), 120 000 tonnes of charcoal were imported in 2014, accounting for 4.7 percent in volume and 9 percent in value of global charcoal imports (FAO, 2016d).

Text contributed by Byoung Il Yoo

Table 5. Overview of policies and measures implemented in sub-Saharan Africa to support sustainable woodfuel value chains

Policy approach	Characteristics	Examples
Bans on woodfuel production or transportation	Difficult to enforce Encourage corruption Create a risk that consumers turn to lower-quality fuels	Attempted in many countries, including Cameroon, Chad, Ethiopia, Kenya, Malawi and the United Republic of Tanzania
Land-tenure and forest management reforms	Important to ensure rights of access and control for woodfuel producers, as well as the right to exclude others from exploiting a given resource Typically implemented as broader strategies, not necessarily linked to woodfuel value chains Common to all examples of successful woodfuel value-chain development, but insufficient on their own to ensure success	Tenure and forest management reforms: with some successful woodfuel value-chain development – Burkina Faso, Chad, the Gambia, Madagascar, the Niger (limited to specific projects), Senegal and the United Republic of Tanzania without significant value-chain development – Democratic Republic of the Congo (private and community forestry), Ethiopia (participatory forest management), Kenya (community forest associations) and Uganda (district-level management)
Licences, quotas and permits	Established as means to formalize, monitor and control resource flows Under private or community forest management, licences and permits can channel revenue to individuals or communities Often require forest management plans, which individuals and small communities can find difficult to develop and implement Licences and permits are more effective when the application process is simple and decentralized Complicated or costly permit systems can act as *de facto* bans, resulting in the same negative outcomes	Use is widespread, with varied results: Burkina Faso, the Niger, Senegal – some degree of compliance with the permit/licensing system Congo, Democratic Republic of the Congo, United Republic of Tanzania – permit systems are in place but obtained by only a small fraction of producers Mali – permits are costly and often ignored Kenya, Malawi – permits are required through a highly centralized application process; few permits are issued, leading to *de facto* ban Zambia – permits are required; adherence to regulations varies with location
Subsidies and taxes	Subsidies – common for electricity, kerosene and cooking gas but rarely applied to woodfuels Taxes – frequently built into licence and permit fees and may be levied on extraction and transportation Frequently circumvented, leading to lost tax revenue Differential taxation – can encourage woodfuel production from community or privately managed resources	Many countries in sub-Saharan Africa have some woodfuel taxation system in place, but the systems vary greatly in detail and coverage Differential taxation has been implemented with some success in Chad and the Niger and with less success in Mali and Senegal
Cooperatives and producer associations	Can provide officials with means to monitor who produces woodfuels and create clear pathways for communication and revenue flows Allow members to pool resources and increase bargaining power in some market conditions	Woodfuel producer cooperatives are common in Senegal, the Niger and Mali In Kenya, charcoal producers are required to form associations in order to obtain production permits. Many associations are registered but few permits, if any, are issued The Sudan has had some success with producer cooperatives

Source: FAO, 2017a

sectoral policies relevant to promoting sustainable wood energy for food security (e.g. forest, energy, environmental, agricultural, food security, and nutrition and health policies) need to be better integrated in recognizing the potential of woodfuel as a renewable and affordable energy source. Table 5 and Box 8 present some policy recommendations developed by FAO for incentivizing sustainable wood energy in sub-Saharan Africa (FAO, 2017a).

Challenges to promoting more sustainable woodfuel production include:

- lack of knowledge and resources for sound forest governance;
- high costs of woodfuel plantations, and competition from wild harvesting;
- insecure tenure and access rights;
- multiple and conflicting interests concerning the use of trees and land for fuel, agriculture and other purposes.

A further challenge is that policy-making is not always based on firm evidence. Mwampamba *et al.* (2013), for example, identified five misconceptions about charcoal frequently held by policy-makers and other stakeholders despite evidence to the contrary; such faulty perceptions have a number of policy implications (Table 6). In the United Republic of Tanzania, a project has been carried out to study the potentials and impacts of biomass energy in order to advocate for policy and regulatory frameworks that support sustainable charcoal production (Doggart, 2016).

Cross-sectoral governance of multifunctional landscapes offers the potential for the equitable supply of both food and energy (Ingram, 2014; Vira *et al.*, 2015). Sustainable and integrated agricultural, tree and forest management systems, integrated food–energy systems, multiple cropping systems and crop rotation offer environmental and socio-economic benefits which include improved access to woodfuel and food security (FAO, 2012).

The use of improved cooking stoves can improve fuel efficiencies and the health and safety of users, as discussed in the previous chapter. Policy options to improve efficiencies need to be tailored to the local context. They require investments

Box 8

Key recommendations for the sustainable sourcing of woodfuels in sub-Saharan Africa

- Multiple measures involving structural changes – such as the devolution of forest management rights – combined with targeted regulatory measures have the most profound and lasting impacts.
- Secure tenure over communally held woodland resources or individually held private land (depending on the context) is particularly important.
- Permit systems must be simple and easy to enforce, with quotas based on simple management plans developed with local participation. Systems under local management, with permits issued by communities or local authorities, function better than centralized systems, but communities must have recognized, enforceable rights over forest resources.
- A successful targeted financial measure is differential taxation to reward harvesting from sustainably managed sources.
- When taxes or permits are implemented, a substantial fraction of the revenue must reach rural communities to incentivize their participation and compliance.
- Transformations take time and can easily be undone by shifts in policy. Efforts to bring about sustainable woodfuel sourcing need to be maintained for long periods and must not be undermined by contradictory policies.

Source: Based on FAO, 2017a

Table 6. Five misconceptions about charcoal, and their policy implications

Misconception	Reality	Misguided policy resulting from the misconception
Charcoal is an energy source primarily for the poor	Poor people cannot afford charcoal but rely on fuelwood collected from building sites and peri-urban forests Charcoal is the preferred fuel of many middle-income families	Charcoal interventions target wrong user groups
Charcoal use for cooking will decrease automatically as a country becomes more developed	Higher income and urbanization are often associated with a switch from fuelwood to charcoal, thus resulting in an increase in charcoal use	Marginalization of the sustainable charcoal sector and of forest and tree management
Charcoal production causes deforestation	Deforestation is mainly a result of agricultural expansion, pastoralism and unsustainable logging; charcoal is a by-product of these processes In the cases where forest areas are cleared for charcoal production, the forest is able to regenerate Charcoal production generates income and can be an incentive for sustainable forest management	Cutbacks on funding for sustainable charcoal production Misguided interventions such as bans on charcoal use, which push charcoal production into illegality and thus exacerbate forest resource degradation
The charcoal sector is economically irrelevant	The charcoal industry in sub-Saharan Africa was worth more than US$8 billion in 2007 (FAO, 2017b) Informal and illegal trade implies high transaction costs Bribes along the charcoal supply chain can represent up to almost one-third of the final price paid by consumers In sub-Saharan Africa, the charcoal sector employs a significant workforce, providing regular income to millions of people Charcoal is a significant source of renewable energy for many countries	Charcoal is considered only in an environmental niche, while its role in the economy and energy sectors is ignored Allocation of national budget resources to the charcoal sector is therefore far below what the sector would deserve
Improved charcoal cooking stoves mitigate deforestation	The impact of improved stoves on charcoal consumption has not been demonstrated; improving the popularity of charcoal use may actually increase rather than decrease fuel consumption	Resources allocated to large-scale cooking-stove programmes without sufficient attention to improving the enabling environment for sustainable forest and tree management

Source: Adapted from Mwampamba *et al.*, 2013

in technology transfer and behavioural change and must be accompanied by policy instruments such as financial and tax incentives and guidelines.

A number of Asian countries (e.g. China, the Philippines, the Republic of Korea and Viet Nam) have demonstrated that agricultural production and food security can be enhanced without compromising forest resources (FAO, 2011b, 2016b; Le, Smith and Herbohn, 2014; McBeath and McBeath, 2010). However, the role of forests and trees in food security is still underappreciated and poorly reflected in

national and international development and food security policies, strategies, programmes and legal frameworks. As a result, opportunities to enhance food security via (agro)forestry sector policy remain limited. This reality signals the need:

- to better appreciate and understand the role of forests and trees and their products, including woodfuel, in food security and nutrition;
- to recognize the necessity of maintaining healthy forests to ensure food and nutrition security;
- to ensure that food security objectives are well integrated in national forestry policies and vice versa.

LINKS TO THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT

In the context of the 2030 Agenda for Sustainable Development, sustainable woodfuel can contribute to a number of the 17 Sustainable Development Goals (SDGs) (Figure 4). First, SDG 7 ("Ensure access to affordable, reliable, sustainable and modern energy for all") includes targets on increasing the share of renewable energy, improving energy efficiency and upgrading technology for supplying energy services.

In the absence of a clear definition of "sustainable and modern energy", the continuing perception of woodfuel as an old-fashioned energy source hinders a progressive view of its potential role in a renewable, affordable energy mix. Sustainable production, efficient conversion and cleaner end uses can enable woodfuel to contribute to achieving SDG 7 as it provides primary cooking energy for one-third of the global population.

Trees in agricultural or agroforestry systems, in producing sustainable woodfuel alongside food crops, also fit objectives to contribute to both food security and agricultural yields, in line with SDG 2 on food security and incomes of smallholders (2.3), ensuring sustainable

FIGURE 4. Synergies between woodfuel and the Sustainable Development Goals

food production systems and resilient agricultural practices that help to maintain resilient ecosystems (2.4) and maintaining genetic diversity of seeds and other plant and animal species (2.5).

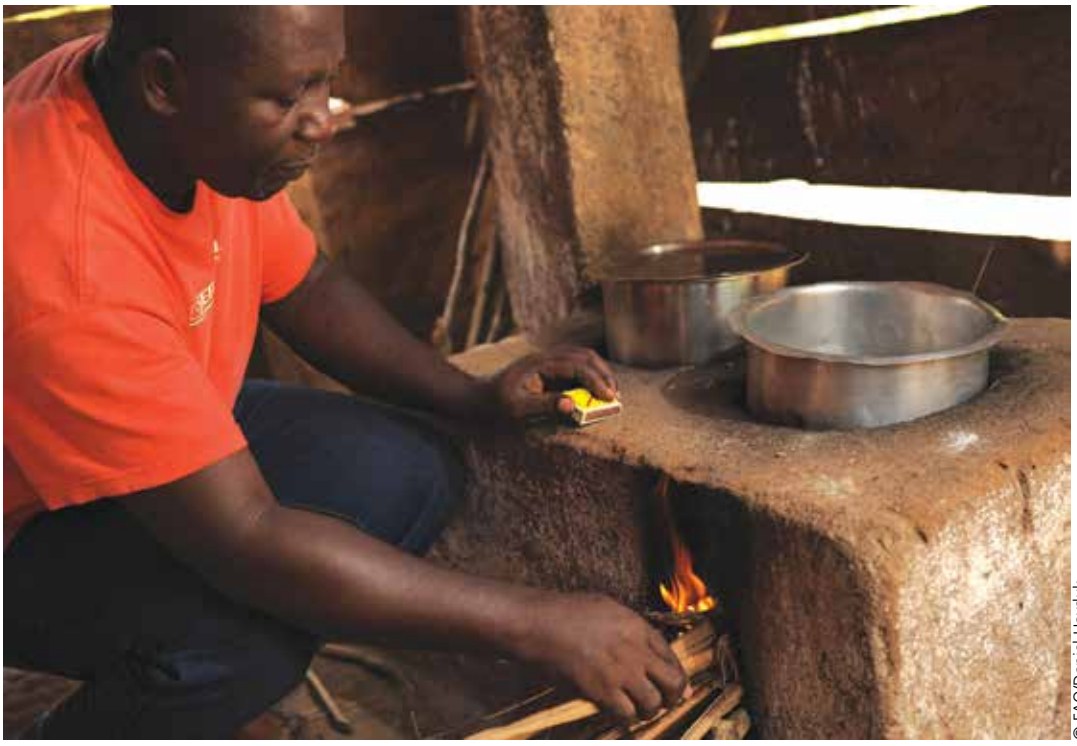
In providing carbon storage and low-emission and renewable energy, sustainable woodfuel production also contributes to SDG 13 (mitigate climate change). SDG 15 (sustainable land use) can also be improved when woodfuel rights and access to sustainable woodfuel sources are clarified, when integrated land-use plans and energy master plans (including wood energy) are used, and when woodfuel is addressed in wider institutional, legal and policy frameworks for agriculture, energy and development (GIZ, 2014; Malimbwi and Zahabu, 2008; Remedio, 2009).

The synergies between wood energy and food and nutrition security mean that sustainable woodfuel use can contribute also to improving health (SDG 3), gender equality (SDG 5) and clean water and sanitation (SDG 6).

KEY RECOMMENDATIONS

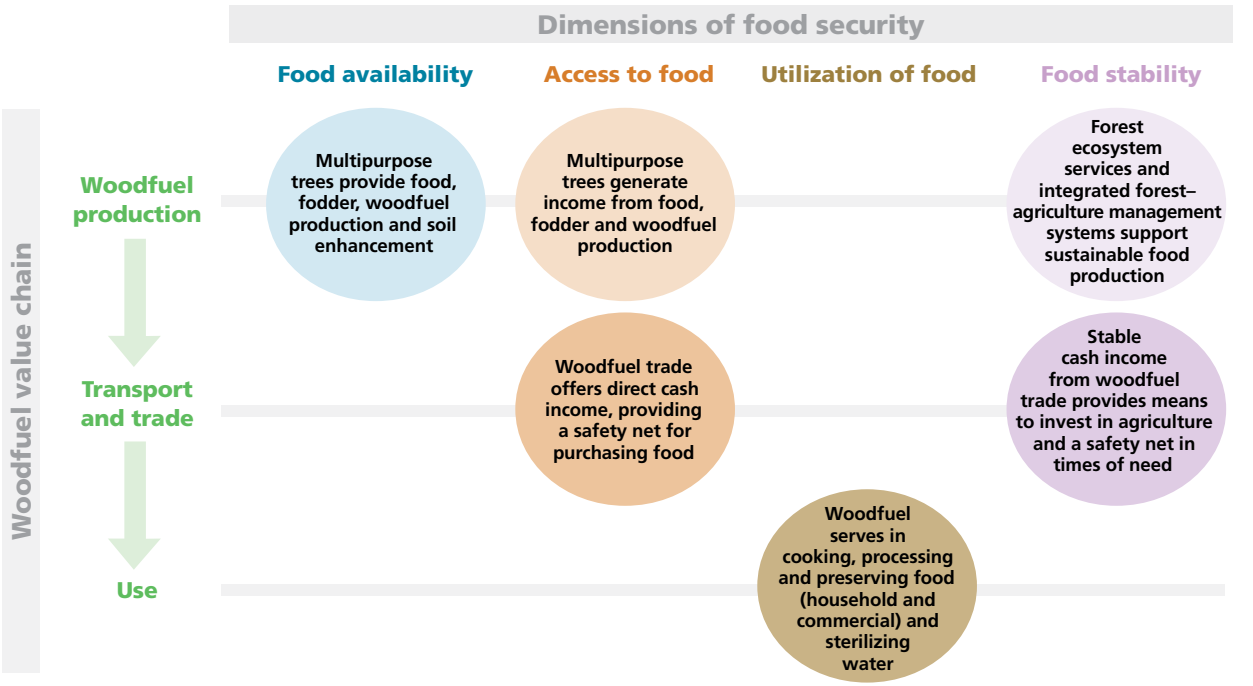
In order to maximize synergies among sustainable wood energy production, trade and use to improve the contribution of woodfuel to the four dimensions of food security, policy-makers are advised to:

- acknowledge the interlinkages among production, trade and use of wood energy and their contribution to all dimensions of food security: food availability, access to food, utilization of food and food stability;
- develop a shared view on how woodfuel can be a desirable, renewable and affordable energy source, distinguishing impacts of sustainable woodfuel use in rural and urban contexts;
- improve the cross-sectoral governance of land, forests and trees to recognize and promote sustainable wood energy as a renewable and affordable energy source for food security and nutrition;
- ensure that sustainable management of wood energy–food systems is accompanied by effective transfer



A man lights an energy-saving stove introduced as part of a project promoting climate adaptation in the United Republic of Tanzania

FIGURE 5. Links between the sustainable woodfuel value chain and food security



of forest and tree tenure rights to community-based or private entities;

- with clear and secure forest and tree tenure rights established, promote community-based forest management, agroforestry, assisted natural regeneration, village woodlots and plantations under simple management plans;
- acknowledge in national energy plans the prospect of dependence on woodfuel in the immediate to mid-term future;
- support forest–farm landscape systems that integrate wood energy and food needs;
- embrace options for more efficient use of woodfuel as part of initiatives for use of multiple fuels and multiple devices adapted to local needs and practices;
- promote the use of wood-industry residues for the production of charcoal and other woodfuels;
- implement strategic planning, combined with fiscal and regulatory incentives for sustainable woodfuel and food production, based on a value-chain approach and facilitated by spatial mapping and policy tools.

CONCLUSION

Woodfuel has a major role in ensuring and sustaining food security and nutrition for one-third of the world's population, and with improved forest and tree management, it can alleviate problems related to ensuring sufficient, safe and nutritious food for those who are food insecure (Figure 5). Particularly in poorer regions and for vulnerable groups in society, food insecurity and dependence on woodfuel for cooking prevail.

Woodfuel has often been considered the main driver of deforestation, when in reality agricultural expansion is the primary cause. Where forest governance is weak, woodfuel has negative impact on forests. But when sustainably managed, woodfuel holds potential to serve as a renewable and affordable energy source contributing to improved food security, environmental protection and climate change mitigation, for both rural and urban areas in developing countries. Woodfuel should therefore be seen as a clear opportunity for improved livelihoods and sustainable natural resource management.

REFERENCES

Adnan, M., Begum, S., Latif, A., Tareen, A.M. & Lee, L. 2012. Medicinal plants and their uses in selected temperate zones of Pakistani Hindukush-Himalaya. *Journal of Medicinal Plants Research*, 6(24): 4113–4127.

Agyeman, K.O., Amponsah, O., Braimah, L. & Lurumuah, S. 2012. Commercial charcoal production and sustainable community development of the upper west region, Ghana. *Journal of Sustainable Development*, 5(4): 149.

Aju, P.C. 2014. The role of forestry in agriculture and food security. *American Journal of Research Communication*, 2(6): 109–121.

Akinnifesi, F.K., Ajayi, O., Sileshi, G., Chirwa, P.W. & Chianu, J. 2011. Fertiliser trees for sustainable food security in the maize-based production systems of East and Southern Africa. *In* E. Lichtfouse, M. Hamelin, M. Navarrete & P. Debaeke, eds. *Sustainable Agriculture*, Vol. 2, pp. 129–146. Dordrecht, the Netherlands, Springer.

Akpalu, W., Dasmani, I. & Aglobitse, P.B. 2011. Demand for cooking fuels in a developing country: to what extent do taste and preferences matter? *Energy Policy,* 39(10): 6525–6531.

Akther, S., Miah, D. & Koike, M. 2010. Household adaptations to fuelwood shortage in the old Brahmaputra downstream zone in Bangladesh and implications for homestead forest management. *International Journal of Biodiversity Science, Ecosystem Services and Management,* 6(3–4): 139–145.

Angelsen, A., Jagger, P., Babigumira, R., Belcher, B., Hogarth, N.J., Bauch, S., Börner, J., Smith-Hall, C. & Wunder, S. 2014. Environmental income and rural livelihoods: a global-comparative analysis. *World Development*, 64(Suppl. 1): S12–S28.

Arnold, J.E.M., Köhlin, G. & Persson, R. 2006. Woodfuels, livelihoods, and policy interventions: changing perspectives. *World Development*, 34(3): 596–611.

Arnold, M., Kohlin, G., Persson, R. & Shepherd, G. 2003. *Fuelwood revisited: what has changed in the last decade?* CIFOR Occasional Paper No. 39. Bogor, Indonesia, CIFOR.

Bailis, R., Cowan, A., Berrueta, V. & Masera, O. 2009. Arresting the killer in the kitchen: the promises and pitfalls of commercializing improved cookstoves. *World Development*, 37(10): 1694–1705.

Bailis, R., Drigo, R., Ghilardi, A. & Masera, O. 2015. The carbon footprint of traditional woodfuels. *Nature Climate Change*, 5(3): 266–272.

Bisiaux, F., Diowo, S., Lufungula, S., Mbono-Wakambo, S., Mafinga, J.-P., Matungulu, P., Lebou, L., Dubiez, É., Louppe, D. & Marien, J.-N. 2013. Les plantations agroforestiere d'*Acacia auriculiformis* de Mampu. *In* J.-N. Marien, E. Dubiez, D. Louppe & A. Larzilliere, eds. *Quand la ville mange la forêt: les défis du bois-énergie en Afrique central*, pp. 135–148. Versailles, France, Éditions QUAE.

Bisiaux, F., Peltier, R. & Muliele, J. 2009. Industrial plantations and agroforestry for the benefit of populations on the Batéké and Mampu plateaux in the Democratic Republic of the Congo. *Bois et Forets des Tropiques*, 301: 21–32.

Boulogne, M., Pennec, A., Dubiez, É., Gigaud, M., Péroches, A., Lavialle, J., Rerolles, J.,

Proces, P., Peltier, R., Marien, J.-N. & Gond, V. 2013. Évolution du couvert végétal et des stocks de carbone dans le bassin d'approvisionnement de Kinshasa. *In* J.-N. Marien, E. Dubiez, D. Louppe & A. Larzilliere, eds. *Quand la ville mange la forêt: les défis du bois-énergie en Afrique central*, pp. 45–62. Versailles, France, Éditions QUAE.

Brouwer, I.D., Hoorweg, J.C. & Van Liere, M.J. 1997. When households run out of fuel: responses of rural households to decreasing fuelwood availability, Ntcheu District, Malawi. *World Development*, 25(2): 255–266.

Brouwer, I.D., Wijnhoven, T.M., Burema, J. & Hoorweg, J.C. 1996. Household fuel use and food consumption: relationship and seasonal effects in central Malawi. *Ecology of Food and Nutrition*, 35(3): 179–193.

Burke, P.J. & Dundas, G. 2015. Female labor force participation and household dependence on biomass energy: evidence from national longitudinal data. *World Development*, 67: 424–437.

Chege, N. 1994. Boiling point: the fuelwood issue restated. *World Watch*, 6(5).

Cooke St Clair, P. 2011. Evolving perspectives on fuelwood. *In* S. Shackleton, C. Shackleton & P. Shanley, eds. *Non-timber forest products in the global context*, pp. 25–26. Tropical Forestry 7. Berlin, Springer-Verlag.

Chidumayo, E.N. & Gumbo, D.J. 2013. The environmental impacts of charcoal production in tropical ecosystems of the world: a synthesis. *Energy for Sustainable Development*, 17(2): 86–94.

Damte, A., Koch, S.F. & Mekonnen, A. 2012. Coping with fuelwood scarcity: household responses in rural Ethiopia. Environment for Development Discussion Paper 12–01. Washington, DC, Resources for the Future.

Doggart, N. 2016. *A review of policy instruments relevant to the integration of sustainable charcoal production in community based forest management in Tanzania*. Technical Paper 51. Dar es Salaam, Tanzania Forest Conservation Group.

Doggart, N. & Meshack, C. 2017. The marginalization of sustainable charcoal production in the policies of a modernizing African nation. *Frontiers in Environmental Science*, 5: 27.

Dubiez, E., Vermeulen, C., Peltier, R., Ingram, V., Schure, J. & Marien, J.N. 2012. Managing forest resources to secure wood energy supply for urban centers: the case of Kinshasa, Democratic Republic of Congo. *Nature & Faune*, 26(2): 52–56.

Endalew, B., Muche, M. & Tadesse, S. 2015. Assessment of food security situation in Ethiopia: a review. *Asian Journal of Agricultural Research*, 9(2): 55–68.

FAO. 1997. *Regional study on wood energy today and tomorrow*. Regional Wood Energy Development Programme in Asia, Field Document No. 50. Bangkok, FAO Regional Office for Asia and the Pacific.

FAO. 2004. *Unified bioenergy terminology – UBET*. Rome.

FAO. 2008. *Climate change and food security: a framework document.* Rome.

FAO. 2011a. *Forests for improved nutrition and food security*. Rome.

FAO. 2011b. *Viet Nam and FAO: achievements and success stories*. Hanoi, FAO Representation in Viet Nam.

FAO. 2012. *Impacts of bioenergy on food security: guidance for assessment and response at national and project levels*. Environment and Natural Resources Working Paper 52. Rome.

FAO. 2013. *Towards food security and improved nutrition: increasing the contribution of forests and trees*. Rome.

FAO. 2014. *State of the World's Forests 2014: enhancing the socioeconomic benefits from forests*. Rome.

FAO. 2015. *Global Forest Resources Assessment 2015.* Rome.

FAO. 2016a. *State of the World's Forests 2016 – Forests and agriculture: land use challenges and opportunities.* Rome.

FAO. 2016b. *Integrated policy for forests, food security and sustainable livelihoods. Lessons from the Republic of Korea*. Rome.

FAO. 2016c. *Forestry for a low-carbon future: integrating forests and wood products in climate change strategies*. FAO Forestry Paper No. 177. Rome.

FAO. 2016d. *FAO Yearbook of Forest Products 2014*. Rome.

FAO. 2017a. *Incentivizing sustainable wood energy in sub-Saharan Africa: a way forward for policy-makers.* Rome.

FAO. 2017b. *The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods*. Rome.

FAO, IFAD & WFP. 2015. *The State of Food Insecurity in the World 2015 – meeting the 2015 international hunger targets: taking stock of uneven progress*. Rome, FAO.

Feyssa, D.H., Njoka, J.T., Asfaw, Z. & Nyangito, M. 2011. Wild edible fruits of importance for human nutrition in semiarid parts of East Shewa Zone, Ethiopia: associated indigenous knowledge and implications to food security. *Pakistan Journal of Nutrition*, 10: 40–50.

Githiomi, J. & Oduor, N. 2012. Strategies for sustainable wood fuel production in Kenya. *International Journal of Applied Science and Technology*, 2(10): 21–25.

GIZ (German Agency for International Cooperation). 2014. *Towards sustainable modern wood energy development: stocktaking paper on successful initiatives in developing countries in the field of wood energy development.* Bonn, Germany.

Gopal, L. & Nagaraju, Y. 2013. Use of renewable energy to enhance sustainability of the mid-day meal program in schools. *Energy for Sustainable Development*, 17(5): 451–457.

Gross, R., Schoeneberger, H., Pfeifer, H. & Preuss, H.-J.A. 2000. *The four dimensions of food and nutrition security: definitions and concepts*. Bonn, Germany, Capacity Building International (InWEnt) & FAO.

Hiemstra-Van der Horst, G. & Hovorka, A.J. 2008. Reassessing the "energy ladder": household energy use in Maun, Botswana. *Energy Policy*, 36(9): 3333–3344.

Ingram, V. 2014. *Win-wins in forest product value chains? How governance impacts the sustainability of livelihoods based on non-timber forest products from Cameroon.* African Studies Collection Vol. 56. Leiden, the Netherlands, African Studies Centre.

Ingram, V., Schure, J., Tieguhong, J.C., Ndoye, O., Awono, A. & Iponga, D.M. 2014. Gender implications of forest product value chains in the Congo basin. *Forests, Trees and Livelihoods*, 23(1–2): 67–86.

Iragi, M. 2016. Des agroforesteries pour protéger la forêt naturelle et lutter contre le changement climatique. *Le Phare*, online edition, posted 23 March (available at www.lephareonline.net/agroforesteries-proteger-foret-naturelle-lutter-contre-changement-climatique).

IRIN News. 2009. Panic, outcry at government charcoal ban. Online edition, posted 16 January (available at www.irinnews.org/news/2009/01/16/panic-outcry-government-charcoal-ban).

Jin, S.-Y. & Reeb, D. 2014. Storage of food, reviewing the value of forest – forest and food security. *World's Food and Agriculture and Fisheries. FAO Korea Association,* 611(56): 38–41.

Kiptot, E., Franzel, S. & Degrande, A. 2014. Gender, agroforestry and food security in Africa. *Current Opinion in Environmental Sustainability,* 6: 104–109.

Kissinger, G., Herold, M. & de Sy, V. 2012. *Drivers of deforestation and forest degradation: a synthesis report for REDD+ policymakers*. Vancouver, Canada, Lexeme Consulting.

Koffi, C.K., Djoudi, H. & Gautier, D. 2017. Landscape diversity and associated coping strategies during food shortage periods: evidence from the Sudano-Sahelian region of Burkina Faso. *Regional Environmental Change*, 17(5): 1369–1380.

Lambe, F., Jürisoo, M., Wanjiru, H. & Senyagwa, J. 2015. *Bringing clean, safe, affordable cooking energy to households across Africa: an agenda for action*. Stockholm, Stockholm Environment Institute.

Le, H.D., Smith, C. & Herbohn, J. 2014. What drives the success of reforestation projects in tropical developing countries? The case of the Philippines. *Global Environmental Change*, 24: 334–348.

Maconachie, R., Tanko, A. & Zakariya, M. 2009. Descending the energy ladder? Oil price shocks and domestic fuel choices in Kano, Nigeria. *Land Use Policy*, 26(4): 1090–1099.

Majule, A., Yanda, P., Kangalawe, R. & Lokina, R. 2012. *Economic valuation assessment of land resources, ecosystems services and resource degradation*

in Tanzania. Dar es Salaam, Global Mechanism & University of Dar es Salaam.

Malimbwi, R. & Zahabu, E. 2008. The analysis of sustainable fuelwood production systems in Tanzania. *In* S. Rose, E. Remedio & M.A. Trossero, eds. *Criteria and indicators for sustainable woodfuels: case studies from Brazil, Guyana, Nepal, Philippines and Tanzania*, pp. 195–224. Rome, FAO.

Masera, O.R., Bailis, R., Drigo, R., Ghilardi, A. & Ruiz-Mercado, I. 2015. Environmental burden of traditional bioenergy use. *Annual Review of Environment and Resources,* 40: 121–150.

McBeath, J.H. & McBeath, J. 2010. *Environmental change and food security in China.* Dordrecht, the Netherlands, Springer.

Mlambo, D. & Huizing, H. 2004. Household responses to fuelwood scarcity: a case study of two villages in Zimbabwe. *Land Degradation and Development*, 15(3): 271–281.

Mwampamba, T.H., Ghilardi, A., Sander, K. & Chaix, K.J. 2013. Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. *Energy for Sustainable Development*, 17(2): 75–85.

Nakada, S., Saygin, D. & Gielen, D. 2014. *Global bioenergy supply and demand projections: a working paper for REmap 2030*. Abu Dhabi, International Renewable Energy Agency (IRENA).

Ndayambaje, J.D., Heijman, W.J.M. & Mohren, G.M.J. 2012. Household determinants of tree planting on farms in rural Rwanda. *Small-Scale Forestry*, 11(4): 477–508.

Ngetich, K.A., Birech, R.J., Kyalo, D., Bett, K.E. & Freyer, B. 2009. Caught between energy demands and food needs: dilemmas of smallholder farmers in Njoro, Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 110(1): 23–28.

Njenga, M., Karanja, N., Munster, C., Iiyama, M., Neufeldt, H., Kithinji, J. & Jamnadass, R. 2013. Charcoal production and strategies to enhance its sustainability in Kenya. *Development in Practice*, 23(3): 359–371.

OECD/IEA (Organisation for Economic Co-operation and Development/ International Energy Agency). 2015. *World Energy Outlook 2015: executive summary*. Paris.

Openshaw, K. 2011. Supply of woody biomass, especially in the tropics: is demand outstripping sustainable supply? *International Forestry Review*, 13(4): 487–499.

Owusu, V., Abdulai, A. & Abdul-Rahman, S. 2011. Non-farm work and food security among farm households in northern Ghana. *Food Policy*, 36(2): 108–118.

Porter, J.R., Xie, L., Challinor, A.J., Cochrane, K., Howden, S.M., Iqbal, M.M., Lobell, D.B. & Travasso, M.I. 2014. Food security and food production systems. *In* C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. *Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects*, pp. 485–533. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK & New York, USA, Cambridge University Press.

Practical Action. 2017. Improved cooking stoves (online, available at https:// practicalaction.org/improved-cooking-stoves).

Remedio, E.M. 2009. An analysis of sustainable fuelwood and charcoal production systems in the Philippines: a case study. *In* S. Rose, E. Remedio & M.A. Trossero, eds. *Criteria and indicators for sustainable woodfuels: case studies from Brazil, Guyana, Nepal, Philippines and Tanzania*, pp. 133–194. Rome, FAO.

Schure, J., Dkamela, G.P., van der Goes, A. & McNally, R. 2014. *An approach to promote REDD+ compatible wood-fuel value chains*. Hanoi, Netherlands Development Organization (SNV).

Schure, J., Marien, J.-N., de Wasseige, C., Drigo, R., Salbitano, F., Dirou, S. & Nkoua, M. 2012. Contribution of woodfuel to meet the energy needs of the population of

Central Africa: prospects for sustainable management of available resources. *In* C. de Wasseige, P. de Marcken, N. Bayol, F. Hiol Hiol, P. Mayaux, B. Desclée, R. Nasi, A. Billand, P. Defourny & R. Eba'a, eds. *The forests of the Congo Basin – state of the forest 2010*, pp. 109–122. Luxembourg, Publications Office of the European Union.

Shindell, D., Kuylenstierna, J.C., Vignati, E., van Dingenen, R., Amann, M., Klimont, Z., Anenberg, S.C., Muller, N., Janssens-Maenhout, G. & Raes, F. 2012. Simultaneously mitigating near-term climate change and improving human health and food security. *Science*, 335(6065): 183–189.

Sidh, S.N. & Basu, S. 2011. Women's contribution to household food and economic security: a study in the Garhwal Himalayas, India. *Mountain Research and Development*, 31(2): 102–111.

Sizer, N., Bass, S., Mayers, J., Arnold, M., Auckland, L., Belcher, B., Bird, N., Campbell, B., Carle, J., Cleary, D., Counsell, S., Enters, T., Fernando, K., Gullison, T., Hudson, J., Kellison, B., Klingberg, T., Owen, C.N., Sampson, N., Vermeulen, S., Wollenberg, E., Shackleton, S. & Edmunds, D. 2005. Wood, fuelwood, and non-wood forest products. *In* K. Chopra, R. Leemans, P. Kumar & H. Simons, eds. *Ecosystems and human well-being: policy responses*, pp. 257–293. Findings of the Responses Working Group of the Millennium Ecosystem Assessment. Washington, DC, Island Press.

Smeets, E.M.W., Faaij, A.P.C., Lewandowski, I.M. & Turkenburg, W.C. 2007. A bottom-up assessment and review of global bio-energy potentials to 2050. *Progress in Energy and Combustion Science*, 33(1): 56–106.

Stloukal, L., Holding, C., Kaaria, S., Guarascio, F. & Gunewardena, N. 2013. Forests, food security and gender. *Unasylva,* 241: 37–44.

Sunderland, T., Achdiawan, R., Angelsen, A., Babigumira, R., Ickowitz, A., Paumgarten, F., Reyes-García, V. & Shively, G. 2014. Challenging perceptions about men, women, and forest product use: a global comparative study. *World Development*, 64(Suppl. 1): S56–S66.

Thorlakson, T. & Neufeldt, H. 2012. Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya. *Agriculture & Food Security*, 1: 15.

UNICEF & WHO (United Nations Children's Fund and World Health Organization). 2011. *Drinking water: equity, safety and sustainability*. Geneva, Switzerland.

UNICEF & WHO. 2015. *Progress on sanitation and drinking water: 2015 update and MDG assessment.* Geneva, Switzerland.

Urmee, T. & Gyamfi, S. 2014. A review of improved cookstove technologies and programs. *Renewable and Sustainable Energy Reviews*, 33: 625–635.

Vira, B., Agarwal, B., Jamnadass, R.H., Kleinschmit, D., McMullin, S., Mansourian, S., Neufeldt, H., Parrotta, J.A., Sunderland, T.C.H. & Wildburger, C. 2015. Forests, trees and landscapes for food security and nutrition. *In* B. Vira, C. Wildburger & S. Mansourian, eds. *Forests and food: addressing hunger and nutrition across sustainable landscapes*, pp. 9–28. Cambridge, UK: Open Book Publishers.

WFP (World Food Programme). 2000. Nutrition and the environment: the importance of wood and water. *SCN News*, 21: 68–69.

WFP. 2012. *WFP handbook on safe access to firewood and alternative energy (SAFE).* Rome.

WHO (World Health Organization). 2006. *Five keys to safer food manual*. Geneva, Switzerland.

WHO. 2008. *Smoke and malaria: are interventions to reduce exposure to indoor air pollution likely to increase exposure to mosquitoes and malaria?* Geneva, Switzerland.

WHO. 2014. *WHO guidelines for indoor air quality: household fuel combustion.* Geneva, Switzerland.

WHO. 2016a. *Burning opportunity: clean household energy for health, sustainable development and wellbeing of women and children*. Geneva, Switzerland.

WHO. 2016b. Household air pollution and health. Fact Sheet No. 292 (online, available at www.who.int/mediacentre/factsheets/fs292).

WISDOM. 2017. Woodfuel Integrated Supply/Demand Overview Mapping [website] (available at www.wisdomprojects.net/global/index.asp).

World Bank Group, AFREA (Africa Renewable Energy Access Program) & ESMAP (Energy Sector Management Assistance Program). 2014. *Clean and improved cooking in sub-Saharan Africa*. Washington, DC, World Bank.

Yoo, B.I., Kim, C.S., Jeon, J.H., Lee, H.S., Chong, S.K. & Yoon, B.E. 2014. *2013 Modularization of Korea's development experience: forest resource development in Korea.* Sejong, Republic of Korea, Ministry of Strategy and Finance & Seoul, KDI School of Public Policy and Management.

Zomer, R.J., Trabucco, A., Coe, R., Place, F., van Noordwijk, M. & Xu, J. 2014. *Trees on farms: an update and reanalysis of agroforestry's global extent and socio-ecological characteristics.* Working Paper 179. Bogor, Indonesia, World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

Zulu, L.C. & Richardson, R.B. 2013. Charcoal, livelihoods, and poverty reduction: evidence from sub-Saharan Africa. *Energy for Sustainable Development*, 17(2): 127–137.

With food insecurity, climate change and deforestation and forest degradation remaining key global issues, this paper highlights the role of sustainable woodfuel in improving the food security of households in developing countries. Food insecurity and a high dependence on woodfuel as a primary cooking fuel are characteristics common to vulnerable groups of people in developing regions. With adequate policy and legal frameworks in place, woodfuel production and harvesting can be sustainable and a main source of green energy. Moreover, the widespread availability of woodfuel, and the enormous market for it, present opportunities for employment and for sustainable value chains, providing further rationale for promoting this source of energy. This paper explains how sustainable woodfuel is closely linked to food security and provides insights in how the linkages could be strengthened at all stages of woodfuel production, trade and use.

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