Tree planting exercise near the village of Moussa, Yangambi - DRC
Photo credit: Axel Fassio/CIFOR

CHAPTER 20

Potential of Biofuel and Bioelectricity Generation from Residues of Tree Commodities in Africa

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Highlights

- Cocoa, coffee, palm, and other tree commodities are dominated by smallholder farmers with limited access to electricity and liquid fuels.
- Residues from tree commodities offer an opportunity for sustainable generation of bioenergy for the amelioration of incomes and local development.
- Tree commodities can increase current bioelectricity production in Africa by 43.39% -290.72%, 85.62-94.72% of current bioethanol production, and more than 100% for biodiesel
- Significant policy development, incentives, and coordination between private, national sectors, regional and continental strategy can significantly boost bioenergy generation.
- A landscape design for developing tree commodities offers significant scope for the sustainability and growth of the sector.

1. Introduction

Over the last decade, the African continent has witnessed an increasing trend in economic growth, population, and, thus, demand for clean energy (IRENA 2015). However, an estimated 600 million Africans lack access to electricity, and another 730 million people depend on traditional biomass energy for cooking and heating (IEA et al 2021). Statistics on access to electricity underscores that only North Africa can boast of high electricity access rates of 98%; sub-Saharan countries are lacking behind with 47% for West Africa, 23% for East Africa, 25% for Central Africa and 43% for Southern Africa. Biomass fuels such as crop residue, fuelwood, charcoal, and dung remain the primary source of energy for heating and cooking to about 81% of

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sub-Saharan households (IEA 2010). Unsustainable production of biomass energy encourages land degradation, deforestation and reduces the carbon sequestration potential of forest and agroforestry systems (Boyd 2008). Health issues such as acute respiratory infections, cataracts, lung problems, cardiovascular diseases, and bronchitis are illnesses that come with inefficient wood-fuel combustion (Piabuo and Puatwoe 2020). Liquid biofuel and bioelectricity from biomass transformation emit less carbon and are cleaner options to fossil fuels and fuelwood (IRENA 2020). Emission reductions from biofuels can go up to 80% compared to fossil-fuel-powered engines (IRENA 2020). Increasing access to energy without endangering the environment and the health of users has been promoted as a sustainable development pathway.

Over the past decade, bioenergy generation from abundant biomass has been promoted as a viable, sustainable energy pathway for the continent (AfDB 2012). African countries and the African Development Bank have underscored bioenergy development as a viable option for energizing Africa. However, significant advances have not been made in developing the sector. High upfront costs and feedstock availability have been highlighted as significant barriers to bioenergy development in Africa (IEA 2019). The AfDB seeks to support bioenergy projects that (i) do not undermine food security and biodiversity, (ii) foster rural development, (iii) achieve a net carbon emission reduction over a lifetime, (iv) reduce poverty and enhance equality, and (v) promote inclusive business models for smallholder farmers. Empirical evidence on the ability of waste from tree commodities to produce clean bioenergy while respecting these conditions is abundant in the literature (Mahlia et al 2019, Mahidin et al 2020). The African Union bioenergy policy framework and guidelines developed in 2014 underscores assessing potential resources for bioenergy generation as one of the key action points. This book chapter contributes to this framework by evaluating the potential for bioenergy generation from tree commodities and enriching this framework with key considerations peculiar to tree commodities. This chapter will seek to answer the following questions: What is the potential for biofuel and bioelectricity generation from tree commodities in Africa? What challenges and opportunities (technology, policy, and cost) abound? What pathways can be used to overcome challenges and barriers?

2. Bioenergy as a green growth pathway

Bioenergy generation from tree commodities can be promoted as a green growth pathway because it enhances inclusive growth (see Table 20.1), promotes sustainable infrastructure, enhances efficient and sustainable use of assets/resources, and ensures resilient livelihoods and economies (Piabuo and Puatwoe 2020). In terms of inclusive growth, the potential of bioenergy projects in job creation is enormous, and it is estimated that 10,000 jobs can be created from a biomass project in a rural region in Africa (IRENA 2020). Energy generation through bioenergy has been a major employer in different parts of the world. In 2016, liquid biofuels created 1.7 million jobs, solid biomass created 0.7 million jobs, and biogas accounted for 0.3 million jobs, with the bulk of these jobs coming through feedstock supply (IRENA 2020). These jobs were created in countries such as Brazil, China, the United States, and India who are currently expanding their bioenergy sources (IRENA 2013).

Bioenergy generation in Africa is an emerging opportunity for youth, and in South Africa, a total of 26,246 jobs were created in 2016 (Deign 2016). For example, about 500 jobs are created by an 800 litres biofuel plant in South Africa. An estimated 4.5 million jobs can be created in Africa by 2030 through renewable energy development with the emergence of off-grid renewable energy entrepreneurs, distributors, installers, and technicians (Yumkella 2019). Bioenergy production in Africa can potentially reduce the reliance of oil-importing countries on crude oil, reduce foreign exchange burden, enhance land restoration, and mitigate greenhouse gas (GHG) emissions. For example, Indonesia saved USD 2,045,050 from reduced importation of diesel due to domestic production of biodiesel (Sanjaya 2019). Emissions from biodiesel are smaller than those from conventional diesel and do not contain Sulphur, thus preventing acid rain.

Table 20.1: *Green growth framework for bioenergy from tree commodities*

Sustainable infrastructure	Efficient/Sustainable use of natural assets	Resilient livelihoods and economic sectors
• Efficient bioenergy generation infrastructure • Easy transport and use • Enhanced water security • Provide multi-purpose solutions	• No change in land use for energy • Maximizes resource use, minimize the ecological impact (reduce carbon emissions), ecological renewable and climate-friendly	• Strengthening disaster management and adaptive capacity • Enhances ecosystem-based adaptation and reduces deforestation for energy. • Serve as safety nets for commodity shocks and enhance socio-economic resilience
Inclusive green growth		
• Green jobs • Innovations and economic diversification • Improved safety and health conditions • Gender and food security		

Source: Adapted from AfDB green growth framework (2014)

The potential of bioenergy in enhancing resilient and economically viable communities and economies cannot be overstated. Access to clean, modern energy is still difficult and expensive to residents in rural and semi-rural parts of Africa. Bioenergy generation from tree commodities can be produced cheaper locally and sold to residents at affordable prices, thus significantly reducing poverty, enhancing food production and consumption (IRENA 2012). Bioenergy generation from tree commodities can also diversify income sources from the crop, thus, creating jobs, local markets, and rural infrastructure (Diaz-Chavez et al 2015). Tree commodities are resources commonly rooted in rural areas, and bioenergy generation from these resources can significantly improve economic and social development through clean energy provision and agricultural productivity. Cheaper access to energy reduces producer prices for food, thus enhancing food and nutrition security (Achterbosch et al 2012, FAO 2010). Duguma et al (2020) underscore that 87% of energy supply originates from agroecosystems; thus, sustainable generation of bioenergy from these systems can serve as viable options for ecosystem-based regenerative energy supply to the continent.

GHG emissions reductions and effective waste management are key positives that come with bioenergy generation from tree commodities. African Economies stand to gain significantly from potential climate change impacts with GHG emissions reduction that come with the use of bioenergy. GHG emissions reduction from palm oil biodiesel has been discussed extensively by scientists, with divergent results. Pehnelt and Vietze (2013) recalculated carbon emissions from palm oil-based biodiesel using different scenarios. Their results indicate that palm oil biodiesel carbon emissions savings potential is above the 19% default rate, 36% Renewable Energy Directive (RED), and 35% sustainable threshold. A projected 60-70 megawatts bioenergy plant from cocoa waste is expected to save 250,000 tons of carbon dioxide. Bioenergy generation from tree commodities requires unique skill sets, and the rural labour force in communities with tree commodities will benefit from a basket of skills that will enhance their employability and self-employment (AfrEA 2011).

3. Advances in bioenergy (liquid, gaseous, and bioelectricity) generation from tree commodities in Africa

3.1. Bioenergy from Palm oil

Palm oil extracted from palm fruits constitutes only 10% of the total biomass from palm plantations, the other 90% residues can reliably be converted into different bioenergy products (Chew and Bhatia 2008). Basiron and Chan (2004) underscore that biomass generated from palm oil in a specific location is seven times higher than from timber. In most parts of the world and some sub-Saharan countries, the waste from palm oil is discarded into water systems, thus causing contamination and complicating the waste management processes. However, this phenomenon has been banned in many developed countries (Kulkarni and Dalai 2006). An average of 50-70 tons of biomass residue is generated per ha of palm oil plantations. Nigeria contributes to 1.5% of global palm oil production and is the largest producer in Africa. The country has developed several policies aimed at improving energy supply from renewable sources and bioenergy. The Nigerian Biofuel Policy and Incentives strategy in 2007 aims to promote bioenergy production in rural areas and reduce adverse health effects from biomass combustion (Ohimain 2010). This policy seeks a 20% biodiesel blend with petro-diesel (B20) to assure a ready market. The National Petroleum Corporation (NNPC) pledged to purchase all biodiesel produced in Nigeria. Other incentives such as tax waivers, loans, and insurance coverage were equally provided to promote bioenergy (Ohimain 2010). Even with the enactment of these policies, palm oil waste as an abundant biomass stock has not been transformed into bioenergy. Progress in implementing policy orientations has been low, with little or no real improvement (Izah and Ohimain 2013). However, the lack of a clear policy road map and implementation by the government accounts for the lack of progress so far. Challenges related to technological infrastructure for bioenergy generation from oil palm remain a major hindrance to implementation (Ohimain 2012, Ohimain 2010).

3.2. Bioenergy from Cocoa

Although Ghana and Ivory Coast account for 59% of global cocoa beans production, the significant amount of biomass left after extraction of cocoa beans is left to rot. The cocoa pot husks are significant and efficient feedstock for bioenergy generation; however, there is no operational plant for bioenergy generation from cocoa waste in the continent. Ivory Coast intends to produce 60-70 MW of electricity using cocoa residue by 2020. In Ghana, significant progress has not been made in generating bioenergy from cocoa waste on a large scale. The government is currently working on a project with the University of Nottingham to generate off-grid electricity for farmers using cocoa waste (Nelson et al 2021). Other producer countries such as Indonesia, Nigeria, Brazil, Cameroon, and Ecuador are equally lacking in policy and bioenergy development actions from cocoa waste (Tsai et al 2018).

3.3. Bioenergy from Coffee

Although bioenergy policies and mandates have been set in major coffee-producing countries, the use of coffee residue for bioenergy generation is quite low or absent (IRENA 2017a). Bioenergy generation in Ghana is principally based on feedstock from cassava, with a 3 million litres biofuel refinery operated by Caltech Ventures (IRENA 2017b). Meanwhile, in Nigeria, sugarcane and cassava are being promoted as a bioenergy feedstock with 60,000 hectares pilot project for bioethanol proposed (IRENA 2016). Many studies have evaluated the efficiency of coffee residues as bioenergy feedstock using different technologies (Chala et al 2018, Zuorro and Lavecchia 2012). However, the large-scale application of these technologies for bioenergy generation is still lacking.

3.4. Bioenergy from Cashew

By the year 2017, Vietnam, India, and Ivory Coast accounted for 22%, 19%, and 18% respectively of global cashew nut production (FAOSTAT 2018). Although Vietnam and India have committed to promoting bioenergy development as a strategy for energy independence and climate change mitigation, cashew nuts and waste have not been used as feedstock (Kumar et al 2018). Multiple test studies have been conducted on the technical potential of generating electricity, biofuels, and biodiesel from cashew and waste (Kumar et al 2006, Bastos and Tubino 2017). However, large-scale application and policy support have been absent in both countries. Additionally, the Ivory Coast is not equally making any progress in transforming waste from cashew nuts to bioenergy.

4. The promising potential of bioenergy from tree residues

The following tree commodities were considered: coffee (*Coffea arabica* and *Coffea canephora*), cocoa (*Theobroma cacao*), oil palm (*Arecaceae*), and cashew (*Anacardium occidentale*). Studies underscore a 40-50% extraction rate (Helwig et al 2002) of residues from agricultural commodities to be sustainable, but this chapter uses a more conservative 20% extraction rate according to Ackom et al (2010). Data on production for the different tree commodities were extracted from FAO (2019) database, residue to product ratio and moisture content for the different tree commodities were extracted from the OECD/IEA report of 2010. The lower heating values were extracted from different papers based on empiric research (NREL 2008, Husain et al 2003, Uzun and Yaman 2015, Mohod et al 2011). Estimates of bioelectricity, biochemical ethanol, and thermochemical syngas to Ficher Tropsch diesel are calculated and presented in Table 20.2. These values represent the production potential for Africa.

Table 20.2: *Biofuel and bioelectricity generation potential from residues of tree commodities in Africa.*

Commodity	Production (Average 2017, 2016, 2015)	Type of residue	Residue to product ratio	Moisture content (%)	Lower heating value KJ/g	Residue (wet tons)	Residue (Bone dry tons)	Residue. 20% Sustainable Extraction (bone dry tons)	Energy potential (bone dry x MK/kg) GJ	Bioelectricity		Biochemical ethanol		Thermochemical syngas to Ficher Tropsch diesel	
										15% efficiency MW h (low)	40% efficiency MW h (high)	(low) liters	(high) liters	Low (liters)	High (liters)
Coffee	1,149,511	Husk	2.10	0.15	12.56	2.41E+06	2.05E+06	4.10E+05	5.15E+06	2.16E+05	5.77E+05	4.51E+07	1.23E+08	3.08E+07	8.21E+07
Cocoa	3,398,572	Pods, Husk	1.00	0.15	15.48	3.40E+06	2.89E+06	5.78E+05	8.94E+06	3.76E+05	1.00E+06	6.36E+07	1.73E+08	4.33E+07	1.16E+08
Oil palm	19,402,457	empty fruit bunch (EFB)	0.25	0.60	15.51	4.85E+06	1.94E+06	3.88E+05	6.02E+06	2.53E+05	6.74E+05	4.27E+07	1.16E+08	2.91E+07	7.76E+07
Cashew	1,713,285	Shell	2	0.15	23.98	3.43E+06	2.91E+06	5.83E+05	1.40E+07	5.87E+05	1.56E+06	6.41E+07	1.75E+08	4.37E+07	1.17E+08
Industrial round wood	28,764,846	forest thinning	0.5	0.4	18.3	1.44E+07	8.63E+06	1.73E+06	3.16E+07	1.33E+06	3.54E+06	1.90E+08	5.18E+08	1.29E+08	3.45E+08
Africa Total									**6.57E+07**	**2.76E+06**	**7.35E+06**	**4.05E+08**	**1.11E+09**	**2.76E+08**	**7.37E+08**

It can be seen from the table above that between 2.76E+06 and 7.35E+06 MWh of bioelectricity, 4.05E+08 and 1.11E+09 liters of biochemical ethanol, and 2.76E+08 and 7.37E+08 thermochemical syngas to Ficher Tropsch diesel can be produced.

4.1. Bio-electricity generation from tree residues in Africa

The production of electricity from biomass is the second-highest after hydro for countries in the Americas, Asia and Europe; however, generation rates are still low for Africa and Oceania (WBA 2018). The continent currently produces 1.94TWh of electricity from biomass; however, significant potentials exist for improvement.

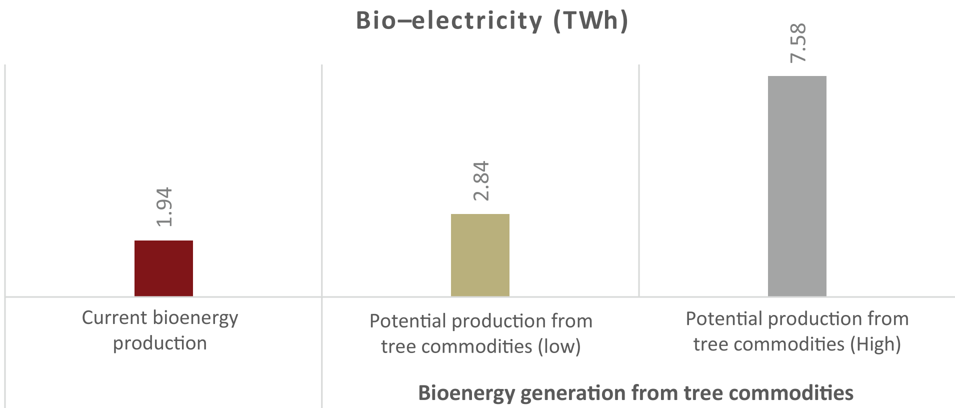

Figure 20.1: *Bioelectricity potential from residues of tree commodities in Africa*

Source: Authors analysis

Figure 20.1 shows the potential of electricity generation from tree commodities of 2.84TWh at low (15% conversion) and 7.58TWh at high (40% conversion) of residue from tree commodities without using extra land. This corresponds to an increase in current production by 43.39% and 290.72%, respectively, in Africa.

4.2. Bio-ethanol generation from tree commodities

As a climate-smart and cheaper option to petroleum, bioethanol has been produced so far in Africa, mainly from crops such as sugarcane, sweet sorghum, maize, and cassava. However, this required extra agricultural land for the cultivation of feedstock. Other issues related to using these energy crops are land-grabbing, increase in food prices, and exploitation of labour. Figure 20.2 shows current levels of bioenergy production and potential levels if waste from tree commodities is converted to bioenergy.

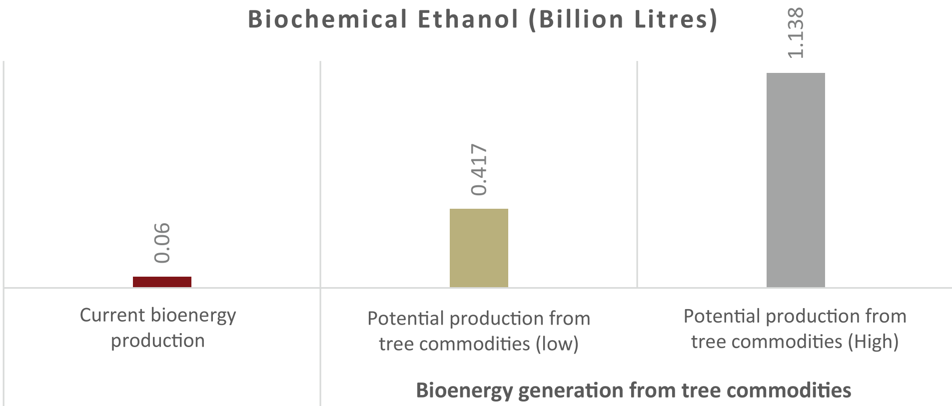

Figure 20.2: *Biochemical ethanol from residues of tree commodities in Africa*

Source: Author analysis

Current production levels of bioethanol in Africa are relatively low, averaging 0.06 billion litres. Tree residues offer a sustainable and more productive feedstock for bioenergy generation; between 0.417-1.138 billion litres annually of bioethanol can be generated from residues of tree commodities within the continent. Currently, biodiesel production is almost non-existent in the literature. Tree commodities offer an excellent opportunity to generate biodiesel production ranges between 0.276-0.737 billion litres annually. Figure 20.3 shows the current level of biodiesel production in Africa and potential levels if waste from tree commodities is sustainably converted to biodiesel.

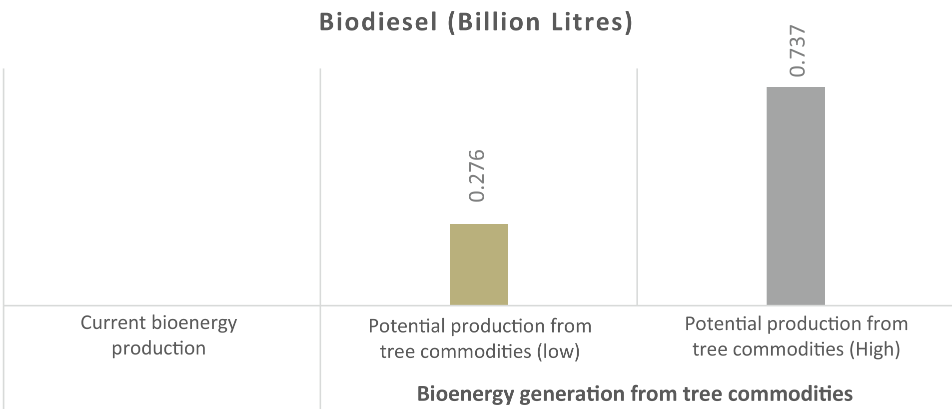

Figure 20.3: *Biodiesel production from residues of tree commodities in Africa*

Source: Author analysis

Contrary to Africa, USA and Brazil are leading biodiesel production with 87% of global production while Asia, South America, and Europe share is distributed evenly (IEA 2019).

5. Harnessing the potential of bioenergy from tree commodities in Africa: Key considerations and lessons

Developing bioenergy in rural areas in Africa can provide cheaper options for cleaner energy. Bioenergy development gives extra value to waste from tree commodities, with higher possible economic benefits to farmers. Increased possibility for small-scale bioenergy generation by farmers serves as an important opportunity for national recognition of the bioenergy sector and its associated benefits. It also serves as better opportunities for remote rural areas to provide feedstock to local processing units contrary to a centralized system. Thus, gaining efficiency through closeness to raw materials and reducing the transport cost of raw materials. Although small-scale ethanol plants are more complex, they are more feasible, with a good number currently operational from pilot projects in Ethiopia and South Africa. They are advantageous because local production processes are simple, and uptake is easy for rural farmers. Environmentally, the option of providing rural communities with cheaper and more efficient energy reduces the pressure on the forest for wood fuel, hence potentially reducing the rate of deforestation by small-scale farmers.

Box 20.1

Advances in biodiesel in Malaysia and Indonesia

Palm industries have also engaged in electricity generation from palm residue in Malaysia; with the first operation commencing in October 2006 with a 7.5 MW capacity (Hu et al 2008). Biodiesel production in Malaysia in 2017 amounted to 720,410 tons of which 235,291 tons were exported. However, this figure is far beyond the 2.7 million potential (Rahyla et al 2017). About 570 million tons of palm biomass is generated annually from palm in Indonesia. In Thailand, since March 2010, 5.9 million litres of biodiesel are produced daily from biodiesel plants using palm oil waste as feedstock (Nimmanterdwong et al 2015). A total of 2.9 million litres of ethanol is produced daily. Although significant progress has been made by putting in place appropriate regulations, national targets, feed-in tariffs and with the increasing demand for energy, major hurdles abound in Indonesia. Governance, public perception, high investment in non-core business of enterprises and inadequate planning security for investors remain as major obstacles to promoting bioenergy from palm oil in Indonesia.

Africa can already learn from Asian countries that are a step forward in producing bioenergy from tree commodity residue. Palm oil-producing countries such as Malaysia and Indonesia have made significant strides in producing bioenergy from palm oil waste. Government support through appropriate policies and finance to kick start the process was critical. For example, Malaysia enacted bioenergy from tree commodities as a key strategic development path to promote the investment act of 1986 (Rahyla et al 2017). This act was followed by significant investment in biofuel R&D and technology transfer through disseminating research among domestic industries. The government equally promoted bioenergy from palm oil by giving out low-interest-rate loans of over US$16 million and federal grants of US$3.3million. Malaysia has been implementing the B7 mandate at the policy level since 2014 and intends to use more feedstock for biodiesel production by implementing a B10 mandate. Indonesia has created a biodiesel mandate to have 20% of biofuels in liquid fuels by 2016 and 30% by 2030. A subsidy program has been set up to facilitate the achievement of this objective. Since 2016, the B20 (20% biofuel in liquid fuels) has been implemented in different phases, taking nationwide effect in 2018. Although Nigeria is the largest producer of palm oil in Africa and the 5th globally, bioenergy generation from palm oil is not well advanced (Egwu 2019). The Biofuel policy and incentives system seeks to promote bioenergy production in rural areas. At the same time, the country equally intends to blend 20% biodiesel with petro-diesel, and the National Petroleum Corporation (NNPC) pledges to buy all the biodiesel produced locally (Egwu 2019). However, the effective processing of palm oil waste has not come to fruition in the country, and bioenergy production remains low or inexistent. This is principal because incentives such as tax holidays, loans, and insurance coverage have not been adequate to promote bioenergy generation.

To develop bioenergy schemes from tree commodities in Africa, it is important to acknowledge potential constraints and opportunities inherent in the way farmers are organized. Small scale farmers dominate tree commodities in Africa; thus, scale economics issues are inevitable. Operating in small units entails capital and operational costs with limited options for benefits of economies of scale; hence, profits can be significantly reduced. The high cost of constructing a processing plant coupled with high capital in rural areas is a major challenge. Integrating bioenergy from rural areas such as ethanol blending can require high transport and logistics costs, hence threatening the cost-effectiveness of the strategy. Production from different small-scale milling units also poses the problem of quality and production standards. Integration into a national grid for ethanol and bioelectricity requires a central quality processing system that requires an extra cost and coordination. Car manufacturers may not be willing to warranty cars using biofuels, especially from different production units with a risk of quality variability.

Most bioenergy projects in Africa are at their embryonic stage and not yet at optimal efficiency levels; most failed before reaching such levels. Many scholars have reported poor planning as one of the main reasons for the failure of these projects (Darkwah et al 2007). Appropriate planning should consider parameters such as climatic conditions for feedstock and the environment's socio-economic and political situation. Technical know-how in sub-Saharan Africa (SSA) in the management of production units remains a major problem. Most countries lack training institutions where experts are trained since most rural communities have limited knowledge on the management of production units and bioenergy.

5.1. Landscape design for bioenergy generation from tree commodities.

Tree commodities shape land-use change and land-tenue systems in Africa; thus, developing bioenergy from residues from these tree commodities should also take a landscape design. This design is critical because it facilitates stakeholder engagement and the integration of a set of objectives (Koh and Ghazoul 2010). It also permits a combination of spatial planning with biomass production, supply chain optimization, vertical and horizontal performance evaluation, education, monitoring, stakeholder engagement, and adaptation management (Dale et al 2015). An adapted and contextualized landscape design for bioenergy generation from tree commodities is underscored in this chapter. At the foundation of this design, policy incentives, frameworks, and coordination are underscored as starting blocks (Figure 20.4).

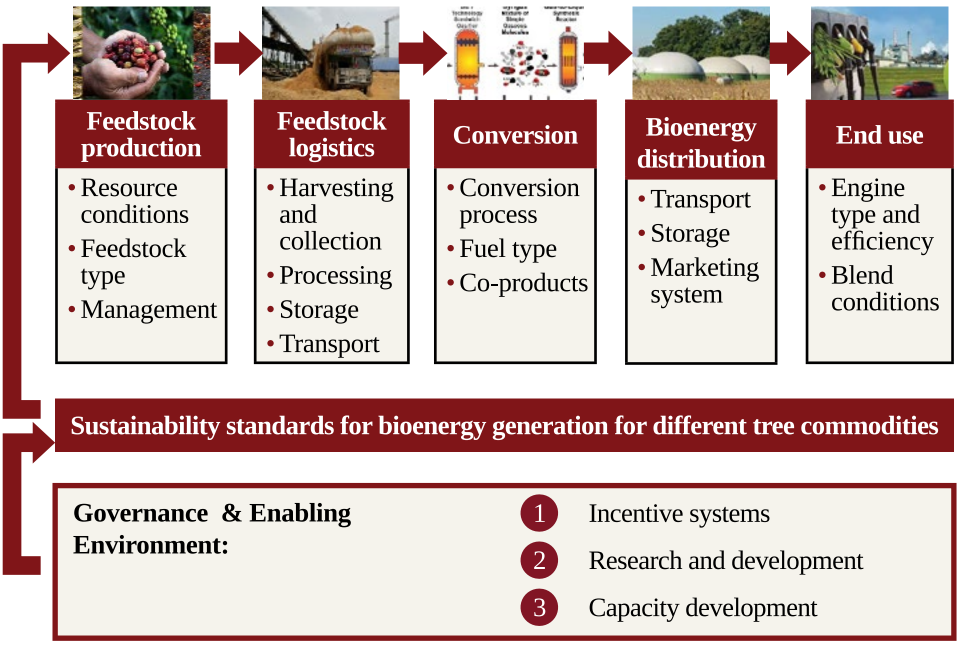

Figure 20.4: *Landscape design framework for bioenergy generation from tree commodities.*

5.2. Policy incentives, research, and development and capacity development

The development and evolution of bioenergy in Africa critically depends on the policies regulating bioenergy generation and use. It also depends on the incentives put in place by policy to promote bioenergy. So far, modern bioenergy sources are more expensive and less competitive than fossil fuels; thus, the speed of adoption and use in an environment characterized by lack of funding and serious capacity gaps is prolonged. Bioenergy policies are relatively less advanced because of the limited use of modern bioenergy since the blending of biofuels and bioelectricity to the national grid is not relatively advanced in many countries (Mitchell 2011). However, advances have been made by several African countries in policy development. Most of these countries have drafted policies, while others have laws voted for application. More advanced countries such as Malawi have put in place blending mandates for biofuel, while other countries such as Ethiopia, Kenya, Mozambique, Nigeria, South Africa, Sudan, and Angola are making significant strides to increase production and introduce blending mandates ranging between 5-10% (Lane 2012). A review of draft policies, bioenergy laws, and regional policies shows an increasing interest from policymakers in promoting bioenergy generation. At the regional level, countries have been working together to promote bioenergy. Smallholders dominate the cultivation of tree commodities; thus, sustainable intensification of production and valorization of agricultural waste is important. This will increase the productivity of farmers, and provide a diversification of incomes. There is, therefore, a need for policy measures to incentivize the private sector to invest in all aspects of the value chain, from production to consumption of bioenergy from tree commodities. Policies and incentives related to bioenergy affect national governments' different aspects, such as finances (tax), environment and forest, agriculture, land-use management, energy, and trade; thus, coordination between different sectors is important. These policies should simultaneously promote afforestation and reforestation through sustainable intensification, thus enabling bioenergy projects to be eligible beneficiaries of Clean Development Mechanism (CDM) projects.

Research and development are also key and should be an integral part of bioenergy development from tree residues. This entails the determination of a contextualized sustainable extraction rate of waste biomass from different tree commodities. Research in conversion technologies and demonstration to different actors is critical to the uptake of bioenergy. Deployment strategies of these technologies should be efficient with a feedback mechanism from end-users to manufacturers for review of the technology. The development of innovative financing and market development schemes that are attractive to private investors and enhance green investments is critical for bioenergy generation. The linkage of different actors and overseas development agencies (ODAs) can sustainably enhance bioenergy development. Attraction to the sector will equally depend on clear existing and established sustainability standards that meet local realities and are coherent with international standards. Innovative standards can be developed through R&D. The policy arm of bioenergy generation from tree commodities is important. It should identify and develop practical policy instruments that enhance rural development, sustainable agriculture, and gender equity. It should also link agricultural and industrial priorities, thus enhancing cross-sector interests.

5.3. Key sustainability standards for sustainable bioenergy generation from tree residues

The sustainability of bioenergy from tree commodities requires that for bioenergy generation to meet today's energy needs, it does not compromise the food and energy needs of future generations (Brundtland 1987). Scientists have promoted the life cycle sustainability assessment (LCSA), integrating three facets of sustainability, to evaluate the sustainability of bioenergy initiatives (Heijungs et al 2010). This entails evaluating the economic, social, and environmental sustainability of all processes of bioenergy generation. Environmental sustainability hinges on an assessment of the upstream and downstream production process with identification of the problems at each stage, tools such as net balance analysis, ecological footprint, energy analysis, GHG life cycle analysis, carbon footprint, material flow analysis, and fuel cycle analysis are key to environmental sustainability assessment (Curran 2013). Using waste from tree commodities does not directly imply the sustainability of bioenergy. Sustainability is not only about GHG emissions savings but for specific use and eventual environmental consequences (Turconi et al 2013). The economic sustainability of bioenergy from tree commodities entails cost-effectiveness, completeness of products, access to markets, and continuous future cash flows. For bioenergy to be socially sustainable, maximization of value addition, health and safety, social benefits and impacts, and public policies should be appropriate.

Biomass certification also emerges as one of the key strategies for sustainable bioenergy production (Richert et al 2006). Setting adequate standards and certification schemes for the different forms of bioenergy can be a viable strategy to assure sustainable production of bioenergy. An appropriate third party with the required know-how, clear and standardized criteria, and indicators is required for effective certification (Lewandowski and Faaij 2005). Certification standards for bioenergy from different tree commodities should be underscored as one of the key aspects of bioenergy strategy when developing a value chain for tree commodities. However, mechanisms should be put in place to ensure that bioenergy certification schemes do not lead to more expensive energy, which can be a big obstacle to the adoption of modern bioenergy. Countries with tree commodities can significantly boost their energy options by developing a sustainable bioenergy system. This chapter estimated the overall potential for Africa. However, contextualized potential based on available feedstock is required before developing conversion technology.

Stakeholder engagement is critical in the development of bioenergy from tree residues. These stakeholders include government authorities, regional and local government, energy-linked parastatals, farmer organizations, NGOs, research institutions, banks, companies, and structures engaged in the tree commodity value chain and other private-sector related institutions.

The selection of conversion technologies needs to pay attention to the availability of feedstock, types of tree residue, geographic location, and human and technological capacity. These are essential at different scales while considering standards at all levels and forms of bioenergy, with clear procedures for small, medium, and large-scale producers.

Developing products that meet market demand requires a good understanding of the local and international market. The necessary infrastructure to facilitate the marketing of products and standards for blending fuels and electricity are key to viable marketing of bioenergy from tree commodities.

6. Conclusion

Green growth, energy independence, healthy energy sources, and sustainable energy have been used repeatedly in literature to promote modern bioenergy in Africa. Emerging literature underscores that residue from tree commodities can provide sufficient feedstock for bioenergy, thus reducing pressure for land and water to cultivate energy crops. The African continent is home to many tree commodities crops; however, bioenergy generation and use from these tree commodities are relatively low. Although the potential of generating bioenergy from tree residues and its contribution to SDGs is considerable, widespread adoption is still embryonic. Policy, capacity, infrastructure, and financial constraints remain major obstacles. However, strides are being made in some countries; thus, appropriate policy coordination and government interest through incentives for smallholder farmers and private sector engagement are key. Continuous R&D with well-developed channels for dissemination and information sharing is important. Training of different stakeholders on sustainable extraction of feedstock, conversion technologies, engagement of policymakers, and enhancing compatibility with end products for local use is paramount for bioenergy development. Developing a viable financial and marketing scheme for bioenergy is imperative, and private sector actors should be incentivized to invest in bioenergy generation by reducing transaction costs and making the sector profitable. Multi-lateral partnerships are key for financial, technical, and capacity cooperation. Linking bioenergy generation to green growth schemes like the CDM projects can also leverage efforts for bioenergy generation from tree commodities.

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