Chapter 2
Enabling Sustainable Bioenergy Transitions in Sub-Saharan Africa: Strategic Issues for Achieving Climate-Compatible Developments

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2.1 Introduction

Bioenergy accounts for 10% of primary energy supply, which is more than the combined contribution from all other renewable energy sources and nuclear power (IEA 2018). However, most of the biomass used for energy in developing countries is in the form of firewood, charcoal, agricultural residues and animal dung for cooking and heating purposes, which is not so different from the way biomass has been used for thousands of years (Mattick et al. 2010). In fact, almost 3 billion persons worldwide use biomass in this manner, including the overwhelming

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majority of households in the least developed countries (LDCs) of sub-Saharan Africa (SSA) (ESMAP 2018).

The supply and share of different types of bioenergy fuels and products vary tremendously by region (Table 2.1) and is closely linked to levels of urbanisation, economic development/growth, standard of living, income, availability of affordable alternative energy sources and national policies (IEA 2018; Bildirici and Ersin 2015). For example, in OECD countries and some emerging economies, there is a diverse mix of modern biomass-based fuels and applications available on the market (e.g. liquid biofuels, solid biomass, biogas) (Table 2.1). This is largely due to policy-driven changes during the past three decades arising from concerns over energy security and climate change (Chum et al. 2011). By contrast, in SSA, more than 90% of the biomass used for energy is in traditional forms (e.g. charcoal, fuelwood) and is mainly used for household cooking and heating, with urban charcoal use driving most of the growth in bioenergy demand during the past two decades (IEA 2018). Charcoal is preferred to fuelwood due to its higher energy density, cleaner burning characteristics and easier storage (Smeets et al. 2012). Electricity, kerosene and liquefied petroleum gas (LPG) offer cleaner alternatives, but generally require substantial subsidies to become affordable for the poor in SSA (Takama et al. 2012; Mudombi et al. 2018b) (Chap. 5 Vol. 2).

The lack of extensive modern bioenergy adoption in SSA lies in stark contrast to its potential, including for liquid biofuels and for other modern gaseous and solid fuels. For example, agricultural harvesting and processing residues in SSA have

Table 2.1 Trends in global bioenergy use (in PJ)

	Biomass type	Africa	Non-OECD Asia	Non OCED Americas	Non-OECD Europe/Eurasia/ Middle East	OECD	World
1990	Municipal waste	<1	3	<1	<1	562	565
	Solid biomass	8206	19,510	3053	731	5658	37,159
	Biogas	<1	<1	<1	<1	64	64
	Liquid biofuels	<1	<1	224	<1	<1	224
2000	Municipal waste	<1	27	<1	131	1046	1204
	Solid biomass	10,466	20,730	2889	54	6284	40,906
	Biogas	<1	49	<1	<1	236	285
	Liquid biofuels	<1	3	269	<1	148	420
2010	Municipal waste	3	241	<1	172	1413	1828
	Solid biomass	13,806	19,491	4173	699	7522	45,692
	Biogas	<1	314	1.4	1.6	520	837
	Liquid biofuels	<1	111	642	8	1679	2220
2015	Municipal waste	3	324	<1	211	1632	2169
	Solid biomass	15,800	19,887	4312	781	7904	48,685
	Biogas	<1	374	9	6565	899	1289
	Liquid biofuels	2	251	933	21	2093	3300

Source: IEA (2018)

been estimated to possibly provide energy equivalent to 4.2 EJ, i.e. more than one-fourth of current solid biomass use in SSA (IRENA 2015). Five SSA countries (Ghana, Mozambique, Nigeria, South Africa, Uganda) have a combined bioenergy potential equal to 117% and 190% of their projected energy needs in 2050 for transport and heat/power, respectively (IRENA 2017).[1] Furthermore, there is substantial potential in SSA to harness biogas both in commercial/industrial settings and at the household level. It is estimated that 18.5 million African households have sufficient dung and water for biogas production (IRENA 2015).

Considering the high bioenergy potential in SSA and the multiple significant sustainability impacts from traditional biomass, the transition to modern bioenergy is important in achieving the long-term development goals embodied in the sustainable development goals (SDGs) and the African Union Vision 2063 (AUC 2015) (Chap. 1 Vol. 1). It is possible that the speed and nature of bioenergy transitions are connected to many other sustainability issues, such that improved understanding of these connections can inform the design of appropriate programmes and policies.

However, catalysing and achieving sustainable bioenergy transitions pose major challenges for most SSA countries. Indeed there have not been major developments in modern bioenergy pathways outside of selected cases and countries such as ethanol in Malawi or bagasse cogeneration in Mauritius and South Africa (Johnson and Matsika 2006; Batidzirai and Johnson 2012; Gasparatos et al. 2015) (see Chap. 3 Vol. 1; Chap. 5 Vol. 2). A host of reasons such as low levels of technology adoption, immature markets and widespread poverty pose major barriers for the transition to modern bioenergy. However, there is a need to make some basic distinctions before considering how to catalyse such a transition.

First, the distinction between "traditional" and "modern" bioenergy is sometimes mistakenly assumed to be a technical issue. In fact, this distinction primarily relates to the improved energy services obtained and new applications developed (Bazilian et al. 2010; Chum et al. 2011; Smeets et al. 2012). Traditional biomass only provides heat or light that is difficult to regulate, often in open fires or simple household stoves that result in high levels of incomplete combustion and the release of indoor air pollutants and greenhouse gases (GHGs). Conversely, modern bioenergy offers higher quality energy services across different carriers (i.e. solid, liquid, gas, electricity) that can be better matched to end-user needs (Faaij 2006; Macqueen and Korhaliller 2011). Nevertheless, the efficiency improvements of modern bioenergy become quite significant when considering the entire supply chain. This is because the same amount of raw materials can provide much higher amounts of useful energy, thus reducing environmental and economic costs. Some fuels and applications, such as improved fuelwood/charcoal stoves and small-scale biogas systems, can be seen as an intermediate stage between traditional and modern energy, in that

[1]It is worth noting that apart from contributing to energy security, well-developed biofuel crop systems such as those based on sugarcane can offer poverty reduction benefits and create long-term livelihood opportunities within rural landscapes that otherwise might not have other major economic opportunities (Mudombi et al. 2018a; von Maltitz et al. 2019) (Chap. 3 Vol. 1; Chap. 5 Vol. 2).

there is an improvement in the quality of energy services, although the efficiency or flexibility might be lower (Barnes and Floor 1996; Foell et al. 2011; Dresen et al. 2014).

Second, the shift from traditional to modern bioenergy can be direct such as, for example, the shift from fuelwood to gaseous or liquid cooking fuels. However, such a shift is more likely to occur indirectly, alongside broader industrialisation pathways and economic development processes, as energy production shifts away from the informal sector and energy use moves outside the household itself (Leach 1992; Silveira and Johnson 2016). As different bioenergy products become more standardised or "commoditised", they also become more flexible in terms of transport and trade (Junginger et al. 2011; Olsson and Johnson 2014). As shown in Table 2.2, bioenergy applications extend across all carriers (i.e. solid, liquid, gas, heat, electricity) and all end-use sectors (i.e. transport, residential, commercial, industry).

Third, bioenergy use transitions in SSA occur at the same time as vulnerability to climate change increases (Olsson and Johnson 2014) (Chap. 1 Vol. 1). At the same time, the continued reliance on bioenergy can put further pressure on land-intensive livelihoods in rural areas, especially those associated with high dependence on traditional biomass and subsistence farming (Chap. 7 Vol. 1; Chap. 2–3 Vol. 2). In this sense, the twin challenges of improving energy access and adapting to climate change can be approached simultaneously if proper support is mobilised for the necessary investment, infrastructure and management systems (Suckall et al. 2015).

It is projected that the demand for traditional biomass will increase in absolute terms in SSA due to the increasing population, accelerated urbanisation and the lack

Table 2.2 Bioenergy options by carrier, end-use sector and market orientation

	Primarily domestic options	Export options	Options not yet widely commercialised
Liquid biofuels (for transport or other uses)	• Unrefined oils • Ethanol • Methanol	• Refined oils • Ethanol	• Pyrolysis oils • Biobutanol • Biogasoline
Solid biofuels (for heat and power)	• Wood pellets • Wood chips • Briquettes	• Wood pellets • Chips	• Torrefied biomass
Solid biofuels (for domestic and institutional uses)	• Charcoal • Agricultural residues • Fuelwood	• Charcoal • Wood pellets • Wood chips	• Biochar
Gaseous biofuels	• Biogas • Synthesis gas	• Biogas (if cleaned and if exportable to gas grid	• Pyrolysis gas
Feedstocks, carriers and co-products	• Agricultural residues • Municipal solid waste • Black liquor • Waste oils	• Oilseeds or oils for refining into biodiesel • High-quality or processed wastes	• Lignin (by-product of lignocellulosic ethanol) • Carbon-rich chains • Bio-hydrogen

Source: adapted from (FAO/UNEP 2011; FAO 2004) of mass adoption of alternative energy options (Smeets et al. 2012) (Chap. 1 Vol. 1). Under most scenarios, traditional biomass will still cater for most energy needs in SSA in 2050 (IEA 2014). Given that this dependency on traditional biomass will also remain a major sustainability challenge into the near-to-medium future, improvements in household energy services would be a key part of the transition towards sustainable bioenergy supply. However, through appropriate strategies and policy interventions this trajectory could be altered to accelerate the transition to modern energy systems and the transformation of rural economies (IRENA 2015).

This chapter aims to outline some of the critical aspects that can enable sustainable bioenergy transitions in SSA. In particular, it highlights four interlinked strategic aims related to the modernisation of biomass for energy (and other uses) that are relevant for climate-compatible bioenergy development. These interlinked strategic issues or aims are to (a) identify and strengthen positive linkages across the different SDGs associated within modern bioenergy transitions in SSA (Sect. 2.2); (b) choose the most appropriate markets and production modes for modern bioenergy (Sect. 2.3); (c) promote integrated landscape approaches for biomass and bioenergy feedstock production to improve resource efficiency and climate resilience, and at the same time reduce land competition (Sect. 2.4); (d) foster synergies between climate mitigation and adaptation (Sect. 2.5). Section 2.6 discusses these priorities in connection to the policy implications and governance requirements for sustainable bioenergy transitions across the continent.

2.2 Identify and Strengthen Positive SDG Inter-Linkages in Bioenergy Transitions

Traditional bioenergy production and use have been linked to multiple sustainability impacts such as forest degradation, GHG emissions, health, poverty, food security, and gender inequality, to mention just a few (Karanja and Gasparatos 2019; Iiyama et al. 2014; van de Ven et al. 2019) (Chap. 7 Vol. 1; Chap. 5 Vol. 2). As a result, the heavy reliance of households in SSA on traditional biomass fuels can complicate the achievement of many different sustainable development goals (SDGs) (Nerini et al. 2018; McCollum et al. 2018).

For example, poor and vulnerable populations, particularly women and girls in rural areas, spend considerable amount of time gathering fuelwood (Karanja and Gasparatos 2019). Households also spend a significant portion of their income to purchase traditional biomass fuels such as charcoal (Takama et al. 2012; Masera et al. 2015). This has been linked with different direct and opportunity costs, as well as energy poverty (Karanja and Gasparatos 2019). Furthermore, biomass dependence can affect cooking habits and dietary choices, which may further directly affect household nutrition and food security (Sola et al. 2016). Indoor air pollution from biomass fuel use is currently one of the leading risks for human health in SSA, and has been linked to high mortality across the continent (Lim et al. 2012; Lakshmi et al. 2010; Lam et al. 2012). The above mechanisms suggest some important linkages between SDGs in the context of traditional biomass fuel use, including especially SDG1, 2, 3, 5 and 7.

In urban areas of SSA, charcoal remains the fuel of choice although of course it is sourced from rural areas (Sect. 2.1). Even though charcoal supply is smaller compared to firewood, charcoal production in SSA may be unsustainable or "non-renewable" and contribute to net GHG emissions, especially in eastern Africa (Bailis et al. 2015). About 20% of harvested woodfuel in SSA (which often involves cutting live hardwood trees) is converted to charcoal (IRENA 2015). This has led to deforestation and land degradation around densely populated peri-urban and urban areas (Ndegwa et al. 2016; Kiruki et al. 2017; Jagger and Kittner 2017). Inefficiencies across the charcoal supply chains and the tendency to use whole trees for charcoal production result in much higher wood consumption compared to direct fuelwood use (World Bank 2009; Smeets et al. 2012; Chidumayo and Gumbo 2013). Furthermore, fuel combustion in inefficient stoves and charcoal kilns contributes significantly to outdoor air pollution and GHG emissions (Shindell et al. 2012; Anenberg et al. 2013; Bailis et al. 2003).[2] The above mechanisms suggest important linkages between multiple SDGs in the context of traditional biomass use, including SDG 7, 12, 13 and 15.

However, it is difficult to halt charcoal production due to the lack of alternative livelihoods across the value/supply chain and/or the affordability of other fuels by users (World Bank 2009; Zulu 2010; Smith et al. 2015; Taylor et al. 2019). So far, the attempts to impose sustainable feedstock sourcing and to formalise and control the charcoal market have had little success in SSA due to the combined effects of poor law enforcement, prevailing land ownership/tenure rules, poor socioeconomic conditions and the high reliance of rural households on charcoal earnings (IEA 2014; Smith et al. 2015; Wanjiru et al. 2016; Taylor et al. 2019). In fact, charcoal contributes significantly to livelihoods in many areas across SSA (Jones et al. 2016; Zulu and Richardson 2013).[3] The above mechanisms suggest some important linkages between multiple SDGs in the context of traditional biomass use such as SDG 1, 8, 9, 12 and 15.

Considering the aforementioned linkages and impacts, transitioning to modern bioenergy production and sustained use can create multiple trade-offs between SDGs through a multitude of different pathways and mechanisms (Table 2.3). Often these pathways relate to multiple SDGs. For example, the transition to modern bioenergy for cooking can have positive health effects (SDG 3) but also contribute to energy access and climate change mitigation and adaptation, goals (related to SDG7 and

[2]It is worth noting that the rate of increase in charcoal use is normally much higher than the rate of urbanisation itself (e.g. due to demographic factors such as the smaller size of urban households compared to rural households) (Hosier et al. 1993). Thus, rapid urbanization and/or commercialisation can result in significantly higher forest degradation from charcoal demand (Santos et al. 2017).

[3]Charcoal production in some dryland areas can also provide a socio-economic adaptation approach when agricultural livelihood opportunities are impacted by climate change (Ochieng et al. 2014).

Table 2.3 Impact pathways of modern bioenergy development and use in the household sector

Impact category	Key relevant SDGs	Impact pathway
Improved energy services	1, 2, 7	– Higher quality of energy services, and overall higher levels of human Well-being, poverty reduction and food security.
Health	3, 11, 12	– Reduced risk of disease from indoor air pollution due to biomass use for cooking, and kerosene for cooking and lighting
Rural development	1, 5, 15	– Employment and income generation (both gains and losses) from the stove sector and bioenergy feedstock production, transport, processing and sales – Income diversification for rural households – Increased time availability (especially for women) to engage in income-generating activities and development initiatives (e.g. self-help groups)
Education	4, 5, 8	– Increased time availability (especially for women and girls) to engage in education and other gainful ventures – Improved conditions (e.g. lighting) to allow better studying
Ecosystem protection	2, 15	– Reduced fuelwood requirement reduces rates of deforestation and forest degradation, with positive outcomes for the provision of ecosystem services and biodiversity conservation
Climate change mitigation	7, 13, 15	– Reduced loss of carbon stocks from deforestation and forest degradation for fuelwood – Reduced emission of black carbon and other GHGs from charcoal production and biomass combustion.
Climate change adaptation	1, 2, 13, 15	– Reduced deforestation and forest degradation improves the availability of natural resources used directly or indirectly to help cope with climatic events (e.g. forest products). – Provision of energy for adaptation measures such as water pumping (e.g. for drinking, irrigation), food processing and storage and medicine storage.

Note: Modern bioenergy fuels can be either used directly in the household sector as alternative fuels for cooking (e.g. ethanol or biogas) or converted to electricity or heat for local use

13, respectively) (Cameron et al. 2016). Conversely, improved access to modern energy services (related to SDG 7) can simultaneously promote climate adaptation and mitigation, and broader development goals related to multiple SDGs such as SDG1 and SDG13 (Suckall et al. 2015) (see also Sect. 2.5).

However, even though most of the outcomes of modern bioenergy transitions are expected to be positive for attaining the SDGs, there could also be some negative or uncertain outcomes. For example, modern bioenergy transitions can cause, in some cases, the loss of employment and income along charcoal value chains, which implies negative trade-offs with SDG8 (Karanja and Gasparatos 2019) (Table 2.3). Other, uncertain outcomes could, for example, relate to climate change mitigation and be linked to the significant emissions associated with land use change (e.g. Chap. 5 Vol. 2) and the difficulty in estimating the emissions of traditional biomass in SSA, due to its informal nature, lifecycle accounting complications and the common practice of using multiple fuels (i.e. fuel stacking) (Masera et al. 2000;

Lee et al. 2013; Cerutti et al. 2015) (Sects. 2.3 and 2.4). This is compounded by the high prevalence of subsistence agriculture often using slash-and-burn methods in rural SSA, which is characterised by low productivity and high GHG emissions (Palm et al. 2013; Johnson and Jumbe 2013). This suggests some important uncertainties at the interface of SDG2, 13 and 15.

Some trade-offs might also emerge due to institutional and/or cultural factors. For example, improving energy access (or similarly reducing energy poverty) is a key enabler of economic development (Sovacool 2012), and at the same time a major possible outcome of clean bioenergy transitions. With increasing income or wealth, households and businesses can switch to higher quality fuels, following the so-called energy ladder, which leads to better energy services (Leach 1992). As the low access to modern energy services in SSA leads to high reliance on the lowest rungs of the energy ladder for cooking and heating, it has been suggested that the thrust of the efforts seeking to catalyse bioenergy transitions should be on accelerating these shifts up the ladder (Bazilian et al. 2010; IEA 2014; Johnson and Diaz-Chavez 2018). However, strong policy incentives for moving up the energy ladder are not always appropriate or desirable, as such shifts also need to consider the prevailing cultural, practical and socio-economic factors (e.g. reliance on multiple fuels and stoves for flexibility at the household and community levels in meeting energy needs) (Masera et al. 2000; Takama et al. 2012).

Identifying such sustainability synergies and trade-offs would be necessary for informing different bioenergy transition pathways. This knowledge would undoubtedly provide a much-needed evidence base that can inform bioenergy transitions in SSA, not the least by allowing them to reach their full potential by maximising multiple positive sustainability outcomes. Integrated research approaches based on sustainability science or the ecosystem services approach have been shown to hold great potential in SSA contexts for synthesising current evidence, assessing the multiple impacts of bioenergy systems and identifying pathways to maximise the positive synergies (Gasparatos et al. 2011; von Maltitz et al. 2016; Baumber 2017; Johnson et al. 2018; Gasparatos et al. 2013, 2018).

2.3 Choose the Most Appropriate Scale, Markets and Production Modes for Modern Bioenergy Options

Until the past decade or so, bioenergy was considered to be primarily a local resource, with international trade being rather limited (Sect. 2.1). Some of the few exceptions were major biofuel programmes and markets in Brazil and United States, and solid biomass for heat and power in a few OECD countries. However, this perception has shifted considerably in the past decade, as the rapidly growing bioenergy demand has also boosted the international trade and commoditisation of liquid biofuels and solid bioenergy (e.g. wood pellets) (Junginger et al. 2011; Faaij et al. 2014; Olsson and Johnson 2014).

Whereas OECD countries invested in modern bioenergy long after phasing out traditional biomass fuels, most developing countries and emerging economies only started investing in modern bioenergy recently and alongside the traditional uses that dominate their energy systems. This has opened up different development pathways for modern bioenergy transitions (Johnson and Jumbe 2013; Johnson and Silveira 2014). For example, in Malawi and Ethiopia, ethanol production for fuel blending in the transport sector has developed over the past decades (see Chap. 3 Vol. 1; Chap. 5 Vol. 2), but traditional biomass still overwhelmingly dominates their domestic energy market (as in practically every other SSA country except for South Africa) (Sect. 2.1).

The growing demand for modern bioenergy (including at the household level) could influence SSA countries to develop both markets simultaneously, targeting both exports and domestic demand (Faaij et al. 2014). In this respect, international trade aspirations could also support domestic agro-industrial development (Batidzirai and Johnson 2012), while the resulting north–south and south–south relations could offer different impetus for trade, technology transfer and land investment in bioenergy, agriculture and forestry (Mathews 2007; Dauvergne and Neville 2009).

However, the actual feedstock type and mode of production can have significant interdependencies with scale economies and market orientation (Batidzirai and Johnson 2012; Gasparatos et al. 2015). Furthermore, the feasible scale of feedstock production and end use can vary considerably between areas. For example, the characteristics of the local economy can determine the availability of labour and agricultural inputs. Similarly, the logistics and economics of bioenergy production and/or conversion may constrain the sourcing of feedstock (e.g. feedstock production becomes uneconomic outside of a certain radius from the conversion facility) (FAO/UNEP 2011).

Figure 2.1 outlines some of the major bioenergy production and use alternatives according to a simple bimodal division between markets (local vs. export) and scale of feedstock production (small vs. large). Small-scale bioenergy production and local use (Type 1) can in principle can have greater development benefits, although these benefits can only be realised when the economic viability is assured, either through public support (e.g. quotas or mandates) or strong local institutions (Gasparatos et al. 2015). On the contrary large-scale bioenergy production has mainly been associated with feedstock production for national and international markets (Type 4) (Gasparatos et al. 2015). Sometimes small-scale production can also be combined with national and/or export markets (Type 3), which has often been the case in some SSA countries for sugarcane production (Mudombi et al. 2018a; von Maltitz et al. 2019) (see Chap. 3 Vol. 1). We should note that both Fig. 2.1 and the examples outlined above are for liquid biofuels (Gasparatos et al. 2015). However, the underlying logic would not be much different for other bioenergy options available in SSA such as solid biomass for heat and power production, biogas or multi-product biorefineries.

Regardless of the scale of bioenergy production and use, there is a need for substantial investments in infrastructure and institutions for enabling bioenergy

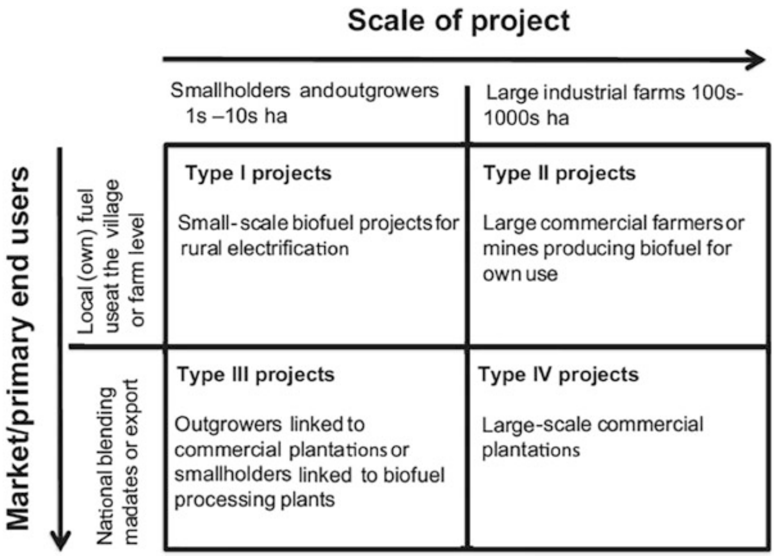

Fig. 2.1 Alternative configurations for bioenergy production and use according to scale and market. Source: (Gasparatos et al. 2015)

transitions (IRENA 2015, 2017; Silveira and Johnson 2016) (Chap. 1 Vol. 1). Such investments would be instrumental for funding the different stages of bioenergy systems, from production (e.g. production systems, ancillary infrastructure), to providing incentives to producers and end users (Souza et al. 2015; da Maia 2018) (see below for more details). An interesting example was the case of jatropha that attracted different types of financing and investment, ranging from foreign direct investments (FDIs) for jatropha-related large-scale land acquisitions (see Chap. 3–4 Vol. 1) to social investments emphasising local benefits through small-scale production and use (Liu et al. 2013; von Maltitz et al. 2014; Gasparatos et al. 2015) (Chap. 5 Vol. 1).

For those bioenergy transitions geared towards meeting domestic demand, it is important to note that, generally speaking, the scale of bioenergy systems is modest compared to those of fossil fuels and nuclear power. Furthermore, the scale can also vary considerably depending on the applications, end-use markets (e.g. local or national) and feedstocks. However, it is this modest scale that makes bioenergy projects and investments well-suited to most SSA countries, especially considering the institutional risks associated with large bioenergy-related investments (e.g. see experience from Clean Development Mechanism projects in SSA) (Lee and Lazarus 2013; Burian and Arens 2014). Smaller scale models do have risks but can also possibly offer greater social benefits in terms of the impacts identified in Sect. 2.2 (Gasparatos et al. 2015). Furthermore, their lower capital investment needs may make it easier to overcome barriers to financing.

For bioenergy transitions geared towards exports, it is important to achieve economies of scale and high economic efficiency for bioenergy production and export. This would require the adoption of at least some level of large-scale production models that can possibly lead to faster transitions and have broader impacts. However, such approaches can also be risky in terms of negative impacts and their effectiveness being curtailed by multiple factors (von Maltitz et al. 2014; Ahmed et al. 2019; Iiyama et al. 2014). The collapse of the jatropha sector across SSA was a painful reminder of the multiple factors that can affect negatively the viability of bioenergy production for exports (von Maltitz et al. 2014; Ahmed et al. 2019). In such models, value addition and export potential could be greater if bioenergy pathways are based on international commodities such as palm oil or sugar/ethanol that are already well-established in terms of agronomic knowledge and international markets (Batidzirai and Johnson 2012; Johnson and Seebaluck 2012; Faaij et al. 2014).

In a sense this issue of choice between local and global markets is inherently reflected in the wide range of global bioenergy potential estimates.[4] At the low end of the spectrum, these estimates correspond to bioenergy catering for less than 10% of the forecasted global energy demand in the year 2050, while at the high end, bioenergy could supply more than the entire global energy demand in 2050 (IPCC 2014). It can thus be argued that the lower end estimates reflect a view of bioenergy as a largely local resource, whereas the higher end estimates view bioenergy as a global market commodity. This divergence implies the emergence of two schools of thought concerning bioenergy in a climate and development context, with the first advocating considerable caution for the possible ecological/environmental impacts of a major global expansion (Beringer et al. 2011), and the other focusing on the possible considerable energy, socioeconomic and environmental benefits of such an expansion (Souza et al. 2015).

Emphasising the domestic use of bioenergy in SSA (rather than export markets) is sound in principle. This is especially true when considering the potential synergies with agricultural development and the significant economic and environmental benefits of shifting away from traditional biomass (Sect. 2.2). However, the scale of energy demand is also low in most SSA countries, and is compounded by the lack of infrastructure and investment options (Chap. 1 Vol. 1), making it difficult to attract sufficient and stable investments to reach economies of scale and/or centres of demand (IEA 2018). Consequently, focusing solely on domestic markets to achieve modern bioenergy transitions can be a lengthy process. In the meantime, the prevailing business-as-usual patterns of traditional biomass production and use can further deepen the cycle of poverty and resource degradation (Sect. 2.2). On the

[4]Modeling results suggest that the global bioenergy potential is largely situated in Latin America and SSA mainly due to climatic and demographic factors (Hoogwijk et al. 2005; Smeets et al. 2007; WGBU 2009; Haberl et al. 2010; van Vuuren et al. 2009; Beringer et al. 2011; Chum et al. 2011; IPCC 2014). A common starting point of these modelling studies is that "food/fibre" should be prioritised, with sustainable bioenergy potential calculated after accounting for the land needed for food production and also excluding deforestation (IPCC 2014; Batidzirai et al. 2016).

other hand, stronger linkages with the larger export markets in the EU and elsewhere could stimulate technology transfer and investment in SSA countries that would otherwise not materialise (Mathews 2007; Johnson 2011; Johnson and Mulugetta 2017) (Chap. 4 Vol. 1). However, strengthening institutions and investment scrutiny would be also needed to increase the long-term viability of modern bioenergy investments, as evidenced from the collapse of the jatropha sector throughout SSA (von Maltitz et al. 2014; Ahmed et al. 2019).

In this regard, the development of bioenergy systems that are flexible enough to cater to both domestic and export markets could be valuable. For example, bioenergy feedstocks such as wood pellets and bioethanol could offer this flexibility (Table 2.2), whereas feedstocks such as biogas and some types of waste (e.g. municipal waste) can be more appropriate for domestic markets for logistical and economic reasons.

In any case, the rural poor must be involved in bioenergy transitions in terms of energy demand and land use if modern bioenergy options are to reach domestic markets in SSA (Johnson and Diaz-Chavez 2018). Subsistence farmers and the rural poor in SSA are extremely constrained in terms of cash and often have almost no disposable income for investing in modern energy options after meeting basic needs (Takama et al. 2012; Mudombi et al. 2018a). Yet they play a major role in their respective national economies through informal markets, especially those related to food and energy (Leach 1992; Sola et al. 2016) (Chap. 5 Vol. 1). The shift from fuelwood to charcoal is a prominent example of a shift from non-cash to a cash economy that occurs partly through urbanisation. This shift has important environmental ramifications (Sect. 2.2) depending on the extent to which charcoal markets are regulated (Zulu 2010).[5]

2.4 Promote Integrated Landscape Approaches for Feedstock Production

Traditional bioenergy production systems can have substantial negative impacts on terrestrial ecosystems in SSA. For example, charcoal production is often associated with various negative environmental impacts such as deforestation and land degradation, particularly in semi-arid areas (IPBES 2018) (Chaps. 1 and 7 Vol. 1). For example, land degradation from unsustainable charcoal production in Kenya and other eastern African areas threatens local livelihoods through declining yields, biodiversity loss and other environmental impacts (Kiruki et al. 2017; Ndegwa et al. 2016). However, the actual links between bioenergy and land degradation

[5]Despite its negative environmental impacts, charcoal production and trade can improve rural livelihoods in terms of cash income (Openshaw 2010; Smith et al. 2015; Karanja and Gasparatos 2019). However, charcoal production does not necessarily reduce poverty in SSA, as revealed by multi-dimensional poverty indicators that incorporate health, housing and other fundamental indicators of well-being (Vollmer et al. 2017).

are rather complex, with charcoal production often being a by-product of other livelihood activities such as land clearing for agriculture (Iiyama 2013; IPBES 2018) (Sect. 2.2). Some countries have attempted to criminalise charcoal trade, but this has been largely unsuccessful due to the lack of affordable energy alternatives and enforcement challenges (Zulu 2010; Smith et al. 2015) (Chap. 1 Vol. 1). On the other hand, fuelwood collection in rural areas is rather different than charcoal use in that it can often be environmentally sustainable (Swemmer et al. 2019), although not necessarily socially desirable in terms of development goals (Sect. 2.2).

However, as discussed above modern bioenergy production can also be rather land-intensive compared to other energy options, especially for Type 2 and 4 modes of production (Sect. 2.3) (Fthenakis and Kim 2009; Emberson et al. 2012; Gasparatos et al. 2017). Land competition between bioenergy feedstock production and food crop production has emerged as a major concern for bioenergy expansion in SSA, especially for first generation liquid biofuels sourced from food crops (Rosillo-Calle and Johnson 2010; WGBU 2009; Gasparatos et al. 2015) (see Chap. 3 Vol. 1; Chap. 5 Vol. 2).[6] Furthermore, bioenergy feedstocks and food crops can compete for water, nutrients and other resources or agricultural inputs, having thus multiple linkages to food security (Wiggins et al. 2015; Jarzebski et al. 2020) (see Chap. 3 Vol. 1).[7] At the same time, there can also be complementarities and co-benefits when food and energy crops are produced and/or used across common systems or landscapes (Johnson and Virgin 2010; Bogdanski 2012; Souza et al. 2015; Kline et al. 2016; Mudombi et al. 2018a).

Landscape approaches across scales, sectors and/or markets can potentially address the competition for land, water and other resources, and help break down the, sometimes unnecessary, distinction between traditional and modern bioenergy. Landscape integration approaches can create opportunities to exploit synergies between food, fibre and fuel production (Dale et al. 2013).[8] Such synergies can occur through common supply chains and infrastructure development. Economic linkages in inputs and outputs can offer complementarities with food production, in terms of the flexibility afforded to producers to adjust over time the production of food, fuel, feed and fibre according to market signals (Bogdanski 2012; Rosillo-Calle and Johnson 2010; Kline et al. 2016).

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[6]This has included in some cases the issue of indirect land use change. Indirect land use change (ILUC) can occur when non-food (e.g. bioenergy) production expands onto agricultural land and displaces food production, which then leads to additional land use elsewhere for food production to compensate the shortfall; ILUC cannot be measured empirically but instead is estimated through assumptions and modelling (Berndes et al. 2013; Finkbeiner 2014; Wicke et al. 2015).

[7]It is worth noting that modern bioenergy systems normally include multiple co-products or waste streams such as bagasse and molasses, respectively, in the case of sugarcane ethanol. The use of such co-products and waste streams can increase land and water efficiency and reduce competition with food (Ackom et al. 2013).

[8]Integrated food-energy systems are a particular class of such systems that can be very important in some SSA countries as they offer both synergies and complementarities between food and bioenergy production (Bogdanski 2012).

Agro-forestry offers another possible approach to reduce the negative impacts arising from land competition between bioenergy production systems and ecosystem services (Duguma et al. 2014; Mbow et al. 2014). In agro-forestry systems, farming practices are adapted to incorporate the multi-functional use of inputs and soil to support tree growth on farms, including ecosystem services such as biological nitrogen fixation (Nair et al. 2009). Feedstock production through agro-forestry systems can be combined with improved stoves to reduce pressure on forests and put fuelwood consumption on a more sustainable path (Iiyama et al. 2014).

Apart from reducing land competition, landscape approaches can also improve bioenergy value chains by emphasising the utilisation of downstream products and factoring them into the initial design of integrated systems (Dale et al. 2013). Such approaches might incorporate broader bioeconomy and land use management perspectives when planning programmes and supporting investments to facilitate transitions away from traditional biomass and subsistence agriculture (Johnson 2017; van de Ven et al. 2019). Furthermore, combining conservation efforts with income-generating activities across integrated landscapes can further offer co-benefits and shift practices away from slash and burn agriculture Rosenzweig and Tubiello 2007; Palm et al. 2013).

When using a landscape lens, bioenergy transitions essentially become a cross-sectoral issue where linkages, synergies and conflicts across agriculture, forestry and bioenergy systems must be addressed (Dale et al. 2013; Johnson and Jumbe 2013; Iiyama et al. 2014). Landscape approaches can incentivise the adoption of various good production practices that can facilitate the useful synergies and reduce the environmental and food security trade-offs of bioenergy production (Milder et al. 2008; Ackom et al. 2013; Kline et al. 2016; see Table 2.4)**.** It must also be noted that the competition for land and biomass between different needs (i.e. food, feed, fibre, fuel) is not necessarily negative. On the contrary it can have positive impact by improving the overall land and resource utilisation efficiency towards a sustainable bioeconomy (Johnson and Virgin 2010; Johnson 2017). The issue is thus not to prevent land use competition but rather to ensure that such competition does not unduly impact the more vulnerable segments of society.

2.5 Foster Synergies between Climate Change Mitigation and Adaptation

As discussed above, modern bioenergy transitions entail multiple processes across different scales and sectors, which collectively have diverse sustainability impacts (Sects. 2.2 and 2.4). Similarly, bioenergy transitions can have important ramifications for climate change mitigation and adaptation in SSA. Although such synergies between climate change adaptation and mitigation could offer an incentive to further promote modern bioenergy transition in the continent, they have, so far, been relatively underappreciated in the SSA context. In this sense, in those contexts that

Table 2.4 Good bioenergy production practices using landscape approaches

	Climate	Ecosystems and biodiversity	Socio-economic	Food security	Energy security
Land use	• Incentives to use degraded or marginal land where feasible	• Enforce high biodiversity exclusion zones	• Land reform considerations in bioenergy programmes • Employment creation efforts in bioenergy programmes	• Food security assessments	• Integrated food-energy systems • Integrated provision of fibre and energy
Water	• Adaptation schemes for reduced water availability	• Protection of wetlands and watersheds • Effluent capture methods	• Systems for enabling water access of smallholders	• Evaluate availability of water for food crops • Advanced irrigation methods	• Bioenergy use for water pumping • Water-efficient energy crops
Soils and nutrients	• Low tillage practices	• Conservation agriculture • Nutrient recovery systems	• Technical support to smallholders for sustainable land management, and agro-chemical/ fertiliser use	• Capacity-building for soil nutrient impact assessments	• Guidelines for removal of agricultural residues
Forests	• Measures to safe-guard high carbon stock areas	• Protection of ecologi-cally sensitive forests	• Organisation of wood and char-coal markets	• Include methods for more efficient woody biomass use in bioenergy programmes	• Energy access evaluation • Incentives for fuel-switching

Source: Adapted from (FAO/UNEP 2011)

it is feasible, strategies can be aimed at win–win–win measures to pursue simultaneously adaptation, mitigation and basic development goals (Suckall et al. 2015).

In terms of climate change mitigation, many studies have noted the high GHG emission savings potential of some bioenergy pathways (Chum et al. 2011; Popp et al. 2011; Albanito et al. 2016). However, the estimated GHG emissions savings can vary widely between different bioenergy pathways due to factors as diverse as the feedstock, mode of production, end use and the different policies and practices governing bioenergy production, use and trade (Smith et al. 2014; Creutzig et al. 2015; Hurlbert et al. 2019). Modern bioenergy transitions can have substantial mitigation benefits if they succeed in curbing the use of traditional biomass fuels such as charcoal, considering the high GHG emissions associated with their production and use (Sect. 2.2).

However, as SSA countries are generally not expected to contribute to large-scale climate change mitigation efforts due to their low overall GHG emissions (Chap. 1 Vol. 1), the main challenge for sustainable bioenergy transitions is how to phase out traditional biomass (and/or use it more effectively and efficiently), rather than maximise emission reductions (Smeets et al. 2012; Karlberg et al. 2015). There are nevertheless many opportunities to achieve large-scale climate change mitigation from bioenergy pathways in SSA, particularly in some agro-industries such as sugarcane where agricultural residues are readily available (Batidzirai and Johnson 2012; da Maia 2018). In this sense, climate change mitigation from bioenergy transitions in SSA could be a valuable co-benefit to attract climate funding to assist the transitions themselves (Lee and Lazarus 2013).

Conversely, the links between climate change adaptation and bioenergy transitions can be less obvious and indirect in SSA. Below we attempt to outline some key, but rather underappreciated, aspects at the interface of modern bioenergy transitions and climate change adaptation in SSA. In particular, we focus on the (a) mechanisms linking bioenergy transitions and climate change adaptation and the (b) possible measures for addressing the adaptation of the bioenergy sector.

One of the most important mechanisms linking modern bioenergy transitions and climate change adaptation is the reduced reliance on climate-induced fuel scarcity. Many rural communities in SSA are highly vulnerable to climate change (especially precipitation changes), as it affects vegetation growth patterns, and thus agricultural productivity and woody biomass availability (Chaps. 1 and 9 Vol. 1; Chap. 2 Vol. 2). In this respect, as such climatic factors affect rural livelihoods and contribute to fuelwood scarcity (Karlberg et al. 2015), then a decreased reliance on traditional biomass fuels through improved energy access could have substantial adaptation benefits (Lambe and Johnson 2009). Another mechanism relates to the reduced reliance on centralised energy systems that are vulnerable and/or prone to disruption. For example, locally available small-scale renewable energy systems (Type 1 systems, Fig. 2.1) could reduce such dependencies, while also offering useful synergies between adaptation and development (Venema and Rehman 2007; Batidzirai and Johnson 2012; Gasparatos et al. 2015).

However, using the same logic as above it is also important to keep in mind that the bioenergy sector is vulnerable to climate change. This because most bioenergy feedstocks in SSA originate from either the agricultural or forestry sectors, which are highly exposed to (and affected by) climate change (IPCC 2014) (Chap. 1 Vol. 1). The impacts of climate change on the bioenergy sector (as well as its prospects for successful adaptation) depend substantially on actual implementation factors such as production site conditions, crop choices, management systems and supply chain structures (Field et al. 2014; Kongsager et al. 2016).

For example, there are significant disparities between the adaptation (and mitigation) potential of different bioenergy feedstocks. Annual agricultural crops (e.g. corn/maize, soybean, rapeseed) used for first generation liquid biofuels may have a negative effect on climate adaptation goals,[9] as they are vulnerable to erosion and drought, which are likely to become more serious in SSA due to ongoing climate change (Rosenzweig and Tubiello 2007; Nguyen and Tenhunen 2013; Smith and Olesen 2010). In contrast, perennial bioenergy crops (e.g. sugarcane, switchgrass, miscanthus) and trees for woody biomass are more resilient to climatic disturbances (thus offering greater adaptation potential), as they can enhance soil stability, reduce erosion risk and improve water retention in soils (Anderson-Teixeira et al. 2009; Wright and Wimberly 2013). It is also worth noting that such feedstocks have generally higher energy yields and GHG emission savings (Fazio and Barbanti 2014; Pugesgaard et al. 2015), offering thus valuable synergies between adaptation and mitigation (Smith and Olesen 2010).

Further, mitigation and adaptation synergies can be leveraged through the adoption of sustainable feedstock production practices. Agro-forestry and other integrated landscape approaches can offer perhaps the greatest potential, despite some negative adaptation and mitigation examples (Table 2.5). Other promising production practices include: (a) landscape management approaches that integrate livestock for biogas production[10] and (b) feedstock production practices that use timber damaged by insects to partially offset forest ecosystem degradation and reduce fire risks by creating incentives to remove dead trees (Lamers et al. 2014).

2.6 Implications for Policy and Governance

Through the different pathways outlined in Table 2.3, modern bioenergy transitions can contribute to multiple SDGs, including SDG 1, 2, 3, 7, 8, 11, 12, 13 and 15 (Sect. 2.2). Indeed, modern bioenergy transitions can become integral parts of climate-compatible development that "minimises the harm caused by climate impacts, while

[9]At the same time, these crops may require large amounts of agricultural inputs (e.g. fertiliser, agrochemicals, fuels), while their yields can be moderate, thus only having modest lifecycle GHG emission savings compared to fossil fuel alternatives (Fazio and Barbanti 2014; Pugesgaard et al. 2015). Implementing best practices could nevertheless facilitate improved scenarios and greater competitiveness for the use of annual crops as bioenergy feedstocks (Souza et al. 2015).

[10]For similar reasons, biogas has become a major part of national adaptation strategies in some SSA countries facing significant land scarcity such as Malawi (Johnson and Jumbe 2013).

Table 2.5 Positive and negative agro-forestry practices for climate change mitigation and adaptation

		Mitigation	
		Positive	Negative
Adaptation	Positive	• Soil carbon sequestration • Improved water holding capacity • Diversification of commercial products • Reduced nitrogen fertiliser use and fertiliser substitution with manure • Fire management	• High dependence on biomass for energy • Overexploitation of ecosystem services • Increased use of mineral fertilisers • Poor management of nitrogen and manure • Emphasis on non-timber forest products
	Negative	• Protection of forest reserves • Forest plantation excluding harvest • Large-scale biofuels export only through international carbon finance	• Use forest fires for pastoral management • Tree exclusion in farmland • Increased reliance on urban charcoal use without land tenure for rural production

Source: Adapted from (Mbow et al. 2014)

maximising the many human development opportunities presented by a low emission, more resilient future" (Mitchell and Maxwell 2010).[11] The goal in this case is to catalyse win–win–win situations rather than focusing separately on development, mitigation and adaptation goals (Suckall et al. 2015). Below, we discuss some critical governance and policy aspects to catalyse the effective integration of bioenergy pathways in climate-compatible development in SSA.

First, it would be necessary to ensure complementarities in national policy frameworks by avoiding the tendency of separating programmes aiming at phasing out traditional biomass from programmes aiming at promoting modern bioenergy. Instead there should be a nested approach in that climate-compatible bioenergy development should emerge from overall development objectives, and then integrate climate change adaptation and biomass promotion strategies across different sectors and scales (Fig. 2.2). In some respect, the missing link is how to better understand the strategic value of modern bioenergy in terms of how a reduction in traditional biomass use can free up biomass for more productive uses (Johnson and Jumbe 2013; Souza et al. 2015). In this sense, the higher productivity of modern bioenergy production (compared to traditional biomass) can thereby contribute significantly to climate-compatible development. Thus, the transition away from traditional biomass fuels in SSA countries would not necessarily mean that biomass use for energy will be reduced in aggregate terms. Rather it means that biomass needs to be used more

[11]There is a wide scope for strategies incorporating climate-compatible and/or "low carbon resilient" development in the context of a green economy. Such strategies focus on innovation and improved management in sectors that have significant climate implications such as agriculture, forestry and transport (Fisher 2013; Stringer et al. 2014; Kongsager et al. 2016).

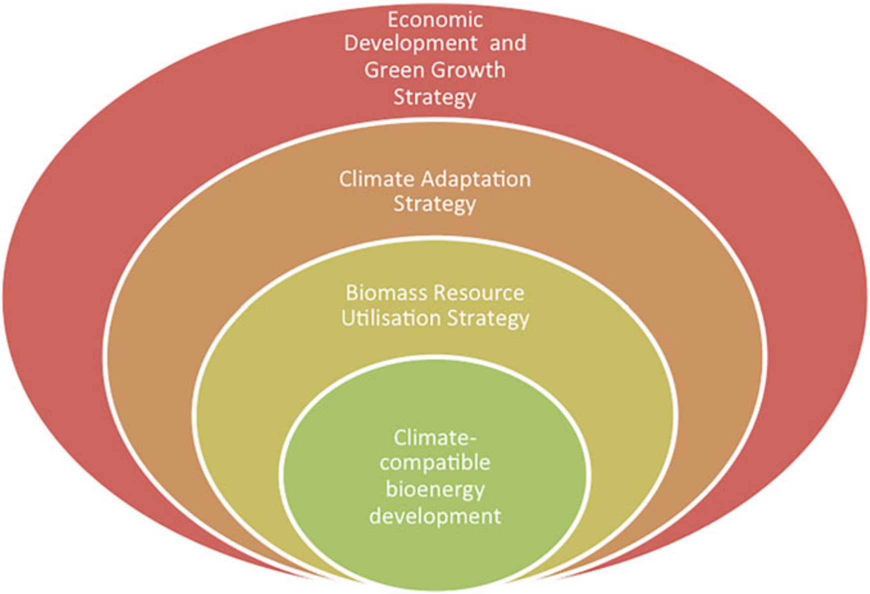

Fig. 2.2 Embedding climate-compatible bioenergy development within broader strategic policy goals

effectively, efficiently and synergistically across its many different uses for food, feed, fuel and fibre (Johnson and Virgin 2010).

Second, there should be concerted effort in national policy frameworks to incorporate mitigation and adaptation measures into broader sectoral policies, particularly in agriculture, forestry and other land-based activities. This would offer a more effective means of implementing climate policies than pursuing specific climate measures per se (Klein et al. 2005). Sectoral approaches to bioenergy development are especially relevant for SSA countries that lack fossil fuel resources, but have sufficient land and water availability. Such countries can benefit from expanding modern bioenergy, while at the same time phasing out traditional biomass, modernising their agricultural sectors and improving forest management. By integrating and coordinating climate policy with agricultural development and forest management, it is possible to create useful synergies for catalysing modern bioenergy transitions, not the least by expanding sustainable biomass supply for both food and fuel, as well as bio-based materials (Johnson and Virgin 2010; Davis 2012; Johnson 2017).

Third, apart from ensuring coherence and complementarity in national policy frameworks, it would be necessary to also consider issues related to national and regional markets (Arndt et al. 2019). The shift of modern bioenergy demand to China, India and other large emerging economies has created new South–South dynamics in technology transfer and energy trade (Dauvergne and Neville 2009). At the same time, the increasing prominence of non-state actors and transnational governance systems in the climate regime and sustainable certification has further complicated the integration of development strategies with national and local priorities (van Asselt et al. 2015).[12] The lack of appropriate cross-level governance systems can lead to the exploitation of precisely those groups that the biofuels expansion is purported to help, namely the rural poor (Dauvergne and Neville 2009). Thus, strengthening national and regional institutions in concert with local governance mechanisms in developing countries would be needed to allow the sustainable exploitation of their considerable bioenergy potential (Sect. 2.1).

Fourth, there are multiple biophysical and policy constraints that need to be navigated in this context of climate-compatible bioenergy development when promoting specific modes of bioenergy production and use. A prominent example are the challenges presented by the high land use intensity of bioenergy systems compared to other energy options (Emberson et al. 2012; Fritsche et al. 2017) when choosing the most appropriate combination of feedstocks, end uses and market orientation in a particular local and national setting (Sect. 2.3). Depending on such factors, bioenergy systems can be either supportive or disruptive in relation to climate mitigation and adaptation (Sect. 2.4). It is thus crucial that the choices made at the policy and implementation levels are well-informed and take these complexities into account.

Fifth, the direct transition route for some household cooking options is rather difficult in practice. The logistical challenges in SSA suggest that there are some advantages for portable and tradeable fuels such as bioethanol. However, the introduction of new fuels and stove technologies is rather complicated, with many factors influencing its effective large-scale uptake, e.g. as witnessed through bioethanol cookstoves promotion in Ethiopia, Kenya and Mozambique (Box 1). Other direct transition routes such as biogas offer similarly clean renewable options and benefits related to land-use management. Such options can indeed offer the most promising pathways for the transition away from traditional biomass, but there are many practical implementation issues that would need to be addressed (van de Ven et al. 2019).

Box 1 Policy Lessons from Bioethanol Promotion for Household Cooking in SSA

Ethiopia has had a long experience promoting ethanol as a cooking fuel. Following its initial introduction in refugee camps, there was a concerted effort to commercialise ethanol fuel through the introduction of highly efficient stoves (Stokes and Ebbeson 2005). However, there has been a competition for bioethanol feedstock (molasses) with other sectors, as well as

(continued)

[12] A prominent example comes from the EU, where the biofuels targets and sustainability criteria have had repercussions globally for markets and policies related to bioenergy, forest and agriculture (Johnson 2011; Pacini et al. 2013; Johnson and Mulugetta 2017) (Chap. 4 Vol. 1).

Box 1 (continued)

competition for the fuel itself with the transport sector. The Ethiopian government has tended to prioritise the transport sector for energy security reasons (Chap. 3 Vol. 1), posing a major barrier for the development of a household bioethanol market, as consumers want a fuel whose availability is assured (Rogers et al. 2013).

Ethanol for cooking was introduced in Maputo (Mozambique) in the early 2010s to divert some of the rapidly increasing charcoal demand (Chap. 5 Vol. 2). This has been the only successful large-scale promotion of ethanol stoves in SSA (Karanja and Gasparatos 2019). The initial success of the large-scale introduction was due to a favourable policy environment, with adoption rates increasing fairly rapidly until supply constraints prevented further expansion (Mudombi et al. 2018b) (Chap. 5 Vol. 2). However, the collapse of the domestic supply for the Cleanstar project, compared with technical and market-related problems also reduced some of the original motivation for ethanol market development as it was intended to boost local production (Chap. 5 Vol. 2).

Kenya has a high national ethanol production capacity that can potentially meet a large share of the domestic household energy demand. However, this bioenergy potential is hampered by unfavourable policies. For example, ethanol is treated as an alcoholic beverage regardless of its end use levying heavy taxes (Karanja and Gasparatos 2019) (Chap. 3 Vol. 1). At the same time, the largest sugarcane factory in Kenya has an annual production capacity of 22 mL of ethanol, but it is not fully utilised. Even though the acceptability and potential of ethanol as a cooking fuel has been strongly demonstrated in pilot studies in Western Kenya, the slow policy progress has prevented uptake of ethanol for household energy use. Instead, this ethanol is used for potable applications or industrial processes, targeting both the local and European markets. The elimination of taxes could make ethanol price competitive to charcoal or kerosene, and possibly contribute to its long-term adoption for household energy use (Karanja and Gasparatos 2019).

Finally, effective bioenergy transitions in SSA must include meaningfully the household sector. If this does not happen then bioenergy transition cannot be effective due to the overwhelming household dependence on traditional biomass and the significant sustainability impacts of this dependence. At the same time, the small scale of the household sector and its informal nature present barriers to the overall bioenergy transitions. The informal nature of the fuelwood and charcoal markets presents considerable sustainability and governance challenges that have created substantial barriers for effective bioenergy transitions. In this sense, transition pathways emphasising fuel-switching are likely to be more effective (van de Ven et al. 2019).

2.7 Conclusions

This chapter discussed some of the key critical aspects that can facilitate sustainable bioenergy transitions in SSA. In particular, it outlined the importance of (a) identifying and strengthening positive linkages across the different SDGs associated with bioenergy transitions in SSA; (b) choosing the most appropriate scales, markets and production modes for modern bioenergy; (c) promoting integrated landscape approaches for feedstock production and (d) fostering synergies between climate mitigation and adaptation.

It must be noted that the choice of these critical aspects has been somewhat selective, emphasising especially how biomass is utilised in the evolving context of land-use change, climate change and development in SSA. Other important aspects, such as water resource management and food security, were somewhat less emphasised, but were highlighted where appropriate. Even though the focus has been on transitions and pathways over time (as opposed to spatial aspects or sustainability assessments at fixed points in time), some important aspects have been highlighted in relation to how sustainability is evaluated and assessed in existing bioenergy policies and related frameworks.

Modernising bioenergy systems is critical for achieving many of the SDGs in SSA. Yet, it must be recognised that it is not simply a local and national issue, but also a regional and international issue. Tradable and environment-friendly bioenergy commodities must be developed across the continent. This could increase their competitiveness with charcoal, which is practically the only widely available current bioenergy commodity. Thus, modern bioenergy markets require deeper international linkages and trade, as much as they require deeper local engagement. This is the dual nature of the bioenergy transition facing SSA.

Bioenergy modernisation can in turn contribute to climate-compatible development, having both environmental and economic benefits. Thus the modernisation process does not have to entail a conflict with ecological or equity goals, but can be rather based on the best combination of local knowledge and global capital. In this respect, the bioenergy transition is not just about meeting the SDGs per se, but also about modernising economies in SSA by using their tremendous natural resource base in a sustainable manner. This virtuous pathway could reduce the tendency observed in many SSA countries to export raw materials (regardless of whether they are renewable or non-renewable). Instead, it could be a starting point for creating value-added knowledge-based products in the pursuit of a sustainable bioeconomy for all.

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