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Research paper

Modelling sustainability of primary forest residues-based bioenergy system

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ABSTRACT

Lack of access to modern energy, such as electricity, liquid fuels and gas, limits socio-economic development in developing countries, particularly in rural communities. Primary forest residues are potential bioresources for producing modern forms of energy beyond traditional biomass, which can be supplied to economic activities in the rural communities. However, variations in production of primary forest residues over time exacerbate sustainability challenges for developing sustainable bioenergy systems based on the residues supply chains integrated with timber production. A model is presented showing dynamics of primary forest residues, as bioenergy feedstocks, stemming from forest plantations management, harvesting systems, and stakeholder influence and interest along the bioenergy production value chain. Using a case study of the Viphya forest plantations established for timber production in Malawi, management and harvesting systems, sawmilling technologies, residues production and post harvesting management were assessed and key sustainability challenges along the residues supply chain have been identified. The decreasing stocks of mature stand over time results from overexploitation for timber production, delayed replanting, high death rate of replanted trees and underinvestment in plantations management. An integrated framework for forest management and bioenergy production can promote sustainable harvesting of mature stand for timber and primary forest residues production through synchronization of harvesting and replanting of timber and establishment of thresholds for harvesting timber to generate residues at a rate that can match with the scale and rate of the bioenergy conversion. The framework can promote stability, availability and reliability of timber and primary forest residues supply for bioenergy production.

1. Introduction

Lack of access to modern energy, such as electricity, liquid fuels and gas, limits socio-economic development in developing countries, particularly in rural areas. Primary forest residues from forest plantations, which are mostly located in the rural areas, provide renewable bioresource for production of various forms of bioenergy that can be supplied to the rural communities. These residues can be converted to generate heat, electricity, liquid transport fuels and biochemicals [1,2]. However, the production of bioenergy from primary forest residues as a by-product of the timber/pulp industries[3] has the potential to present challenges to availability and security of supply of the residues to a conversion plant due to seasonality, variation of quantities and physical state. In addition, it can affect the sizing of scale of operation of the bioenergy conversion plant and the availability, reliability and energy yield of bioenergy over time. The variations over time in harvesting the mature stands for timber/pulp production are as a result of variations in demand for timber/pulp or changes in policies and practices governing management and harvesting systems and technologies in forest plantations.

In addition, the variations in production and supply of primary forest residues for bioenergy production can have significant impact on planning for investment in bioenergy conversion plant, optimum conversion plant scale and bioenergy supply to meet the energy needs of the end-users, which in turn can decrease the motivation and interest of the end-users (key stakeholders) to participate in the bioenergy value chain. Refs. [4,5] have asserted that the harvesting methods, site characteristics, logging and sawmilling technologies and sawyers (operators) capability to operate the milling technologies influence residues generation in the wood industry. While large amounts of residues generated in the timber/pulp industries can positively influence the amount of bioenergy and biochemicals that can be produced at a conversion plant, excessive primary forest residues production per type of sawmilling technology per unit of mature stand can influence rapid depletion of stocks of mature stand in forest plantations over time, which may lead to sharp decline in stocks of primary forest residues for

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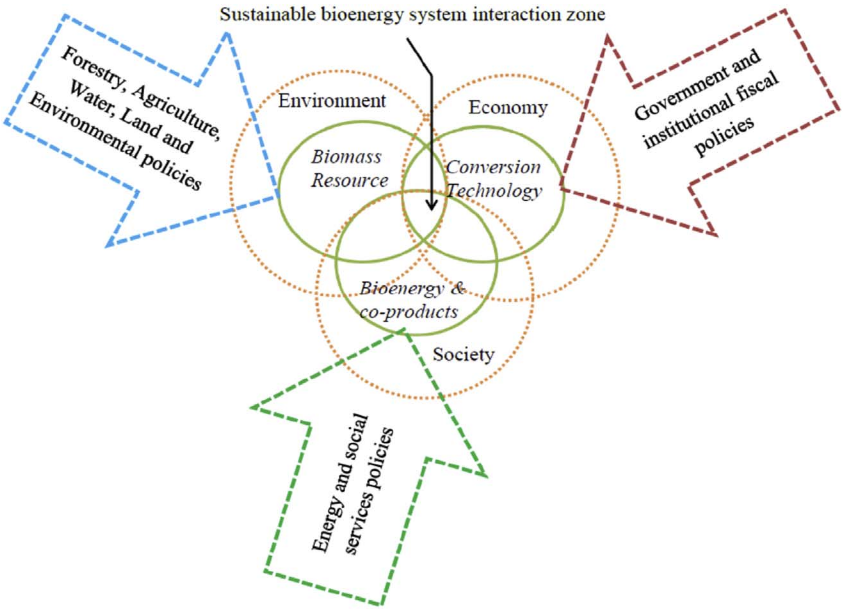

Fig. 1. The interconnectedness of bioenergy production with the ecological, economic and social environments, sectoral policies.

bioenergy production ([6]. Thus, bioenergy production from primary forest residues is complex, involving many interconnected and interacting factors.

The complexity of bioenergy production is exacerbated by the interdependence, interconnectedness and the interactions of the bioenergy system with the ecological, economic social factors [7] and with multifaceted policy/governance frameworks [8] as shown in Fig. 1. Forest policies are intended to affect utilisation and conservation of forest materials and are controlled by the government forest departments [8]. However, forest policies do not operate as standalone stratagems. Forest policies are interconnected and interact continuously with non-forest policies which have significant impact on forest use [8]. Sustainability of primary forest residues-based bioenergy systems is complex multifaceted governance, technical, environmental, economic and social problem. Modelling sustainability of primary forest residues based bioenergy production requires a holistic approach with inherent capabilities to reveal interrelationships and interactions (the feedback structures) at play in the system as a whole.

This study has used the system dynamics (SD) modelling methodology [7,9–13] to develop a model for sustainable production of bioenergy from primary forest residues using Viphya forest plantations in Malawi as a case study. The model, consisting of (1) harvesting of mature forest stand, (2) replanting of harvested area, and (3) a primary forest residues utilisation sub models, provides a better understanding of points of high leverage in the forest supply chain. The purpose is to evaluate the potential sources of variations over time (dynamics) in production and supply of primary forest residues, which can affect the availability of the forest residues for developing a sustainable bioenergy system. Specifically, the model is identifying the state-limiting processes where policy and technical innovations can promote positive and sustainable bioenergy/timber production nexus in forest plantations established and managed exclusively for the purpose of timber production. Furthermore, by using a systems thinking approach, the model is developed to evaluate the cause-effects relationships between process operations in the bioenergy systems and policies that govern the management and harvesting of the Viphya forest plantations. Therefore, identifying specific points in the value chain where either process or policy innovations or both can lead to stability in the flow of the residues to a biomass conversion plant for bioenergy production, in this case, electricity. Thus, the model can show where together, rather than singly, policy and technical innovations can lead to sustainable integration of bioenergy and timber production in forest plantations management.

The approach promotes the analysis of feedback structures that generate the dynamic behaviour intrinsic in complex social and multidisciplinary systems [9–13] such as bioenergy systems (Fig. 1). The SD modelling methodology provides opportunity of modelling systems that adjust to changing circumstances over time [10] with the objective of improving undesirable performance (behaviour or situation) of system [11]. Changes in the policies that govern the forest and energy sectors and practices in the forest plantations can cause significant variations in the bioenergy production value chain.

In addition, SD modelling enables both qualitative and quantitative modelling of internally generated feedback processes and time delays involved in the dynamic behaviour throughout the whole system networks. Therefore, the approach provides opportunity to model qualitative social variables of power/influence, interest, motivation and willingness to pay for energy services of key stakeholders in the value chain. In addition, it enables detection of points in the system where effected small change can result in significant change in system behaviour (points of high leverage) and development of efficient policies/management strategies necessary for the stability of system [8,9]. Furthermore, assessment of feedback processes and time delays in the forest residue and bioenergy networks leads to identification of potential sources of intermittent production supply of the residues and variations in bioenergy production over time. Overall, the model would help in identifying the potential enablers and dis-enablers to sustainability of the integrated timber and bioenergy production systems.

Overview of Malawi energy sector and potential for forest residues-based bioenergy production.

Provision of sustainable energy, especially to the rural and semi urban households, is one of the main challenges facing development of the energy sector in Malawi. Only 1% and 35% of the rural and the urban proportions of the population respectively have access to grid electricity. Thus, about 98% of the rural and semi urban households in Malawi rely on traditional biomass in the form of firewood and charcoal for all the energy needs [16–18]. Fuelwood is collected from indigenous forests and is unsustainably burnt in inefficient cook stoves [17]. However, despite the challenges besting the biomass sub-sector of the energy sector in Malawi, other bioresources such as primary forest residues from forest plantations are poorly managed and underutilised.

Significant quantities of primary forest residues are produced from logging and sawmilling processes in Viphya forest plantations (Fig. 2), which form the largest single block of forest plantations in Malawi