CHAPTER 10

Bamboo

Potential for bioenergy and landscape restoration in Indonesia

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Abstract: The growing demand for energy in Indonesia is driven by population growth, urbanization and economic development. Meeting this energy demand while reducing dependence on fossil fuels is vital. As Indonesia has a rich biomass base, bioenergy has become an important component of the nation's energy agenda. However, a crucial problem with bioenergy production is its potential impacts on food security, the environment and biodiversity. In this context, we discuss the characteristics, benefits and challenges of using bamboo, a perennial grass, as a potential provider of bioenergy feedstock in Indonesia. We describe the fuel characteristics of bamboo and the possibility of aligning its cultivation, production and utilization with environmental and development agendas. Its rapid growth, long root systems, easy maintenance and ability to grow in harsh conditions indicate its potential for use in restoring degraded lands. Therefore, we recommend in-depth research on the social, ecological and economic feasibility of using bamboo for bioenergy production.

Keywords: sustainable energy, land restoration, bamboo utilization, resource production
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10.1 Bioenergy in Indonesia

Indonesia is the most populous country in Southeast Asia and is one of the fastest growing economies among the G20 nations. Indonesia's energy demand has increased significantly in parallel with its population growth, urbanization and economic development (National Energy Council 2016). The country's primary energy sources are fossil fuel based, with coal, oil and gas accounting for the largest share of its energy mix (Ministry of Energy and Mineral Resources 2017). The Government of Indonesia (GoI) has pledged to reduce greenhouse gas (GHG) emissions on the path to decarbonizing its economy. Through its Nationally Determined Contribution (NDC), submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016, Indonesia has committed to reducing GHG emissions unconditionally by 29% compared to a business-as-usual scenario by 2030, and by 41% with international help (GoI 2021). Meanwhile, Indonesia continues to face challenges in its energy sector. Although national energy security is improving, it remains below average and is less satisfactory than in developed and many other developing countries (Erahman et al. 2016). Many rural areas are still deprived of modern energy sources and largely depend on the direct burning of traditional bioenergy sources such as fuelwood, which leads to health problems (Huboyo et al. 2015) and has environmental impacts (Masera et al. 2015).

Ensuring universal access to affordable, reliable and clean energy services is the cornerstone of sustainable development as it is intrinsically linked to many other goals, such as no hunger, good health and well-being, poverty reduction and climate action (Griggs et al. 2017). Through its National Energy Policy, the Government of Indonesia is committed to providing energy to its growing population to help facilitate economic development and improve the well-being of the 11% of its population currently living below the poverty line. The policy emphasizes energy diversification, environmental sustainability and the utilization of domestic energy resources. As the international community is seeking affordable and clean renewable energy as a response to the current UN-driven sustainable development goals (SDGs), Indonesia is also looking to expand the share of renewables in its energy mix, which in 2020 stood at 11.20%. The country aims to increase this figure to 23% by 2025 (Ministry of Energy and Mineral Resources 2021), with bioenergy expected to contribute the highest share at 10%. Bioenergy is an important renewable energy produced from plant biomass and plant-derived residues and wastes to generate heat or electricity, or to produce liquid fuels for transport (Souza et al. 2015). It includes solid biomass (e.g., charcoal), liquids (e.g., bioethanol, biodiesel), and gases (e.g., biogas) produced from plants, wood and agricultural waste, among many other feedstocks. By 2025, bioenergy is projected to contribute to power plants with a total capacity of 5.5 MW, with 13.9 million kilolitres of biofuel; 8.4 million tons of biomass; and 498.8 million m^3 of biogas (GoI 2017).

Indonesia has vast land resources with large variations in elevation, climate, soil and physiographic conditions. This makes it possible to cultivate various types of plants for bioenergy production. However, if not planned and managed appropriately, bioenergy plantation expansion may lead to competition for land and water, and result in negative impacts on food production and biodiversity conservation (Popp et al. 2014). To avoid negative impacts on food security and biodiversity, and to diversify bioenergy production, it is important to identify suitable crops for use as bioenergy feedstock. In this context, this chapter discusses bamboo, a perennial grass, as an alternative raw material for sustainable bioenergy production in Indonesia through a review of scientific publications, reports and other grey literature to synthesize information on the benefits of using bamboo for bioenergy production.

Bamboos are distributed widely throughout the tropics and subtropics, and are the most widely utilized flowering perennials of family Poaceae, with its nearly 1,500 species under 87 genera (Ohrnberger 1999). Human use of bamboo dates back thousands of years. Traditionally, bamboo has been used as a source of food, fibre and fuel in Indonesia. The strong and flexible woody stem of bamboo is also used as a construction material and is frequently called the "timber of the poor". In recent years, modern technology and demand for sustainable goods and services have expanded the utilization of bamboo beyond its traditional uses. For example, it is processed to design and develop durable tools, furniture and building materials. Currently, it can be utilized in many ways; in fact, it has more than 1,500 applications (Lobovikov et al. 2005). Due to its fuel characteristics, high productivity and short rotation, bamboo is now being explored as a potential feedstock to substitute fossil fuels for electricity power generation (Singh et al. 2017). Even though bamboo has been used traditionally in Indonesian culture for centuries (e.g., direct combustion for cooking), its use as a feedstock for modern bioenergy production is relatively new and is still in its infancy.

10.2 Energy properties of bamboo

As with other bioenergy crops, energy can be recovered from bamboo biomass in three main ways: thermal, thermochemical and biochemical conversion (Boyle 2004). Thermal conversion through direct combustion in the presence of oxygen is the most common way of converting solid biomass to energy (Demirbas 2001). The traditional method in Indonesia is using bamboo as fuelwood to generate heat for household purposes, such as cooking and boiling water. However, these conventional applications are relatively inefficient, often result in high indoor air pollution, and are a major health concern in the developing world (Fullerton et al. 2008). At the industrial scale, biomass like bamboo can be used in power plants to produce heat and power for electricity and district heating plants (Eisentraut and Brown 2012). The heat produced by direct biomass combustion in a boiler under controlled conditions can be used to generate electricity by running a steam turbine or engine. Direct combustion in power plants is the cheapest and most reliable route to producing power from biomass in standalone applications (IEA 2009).

Table 1. Fuel characteristics of bamboo compared to other biomass sources

Biomass Type	Ash (%)	Moisture (%)	Volatile Matter (%)	Heating Value (kJ/g)
Rice husk	12.73	12.05	56.98	14.63
Palm shell	3.66	12.12	68.31	18.44
Corn stalk	3.80	41.69	46.98	11.63
Bamboo	2.70	5.80	71.70	17.58
Acacia *	0.36	11.2	65.7	17.40

Sources: Sritong et al. 2012; Marsoem and Irawati 2016*

Another more efficient thermal conversion method is pyrolysis. Pyrolysis is the thermal degradation of biomass at a moderate-to-high temperature in the absence of oxygen. It can be used to convert bamboo biomass to solid fuels (charcoals), liquid fuels and gas (syngas) (Kerlero and Bussy 2000). Bamboo charcoal can be used as a fuel in the same way as coal, and it is a by-product of the biomass gasification process. Liquid fuels or pyrolysis fuels can be processed in a biorefinery to produce biofuels, while syngas can be used to produce power or electricity. In biochemical conversion, different strains of microorganisms are used to transform biomass to biogas or biofuels. The basic principle of biochemical conversion is the fermentation of sugar or other substances in the bamboo biomass into (bio)ethanol, methane and other fuels. Thus, bamboo biomass can be utilized in a variety of forms.

Bamboo has good fuel characteristics, such as high heat value and volatile content, and lower ash and moisture content, which makes it a suitable crop for bioenergy production (Scurlock et al. 2000; Sritong et al. 2012). In addition, in comparison to other biomass, bamboo has high cellulose and lignin content (Kuttiraja et al. 2013). Although these properties may differ according to species, location, maturity stage and management practices, among other things (Kumar and Chandrashekar 2014), in general, its overall heating value and composition lie somewhere between herbaceous biomass and hardwoods. The fuel characteristics (e.g., heating value and chemical composition) of bamboo are similar to those of other dedicated biomass feedstocks. Table 1 shows the fuel characteristics of giant asper *(Dendrocalamus asper)*, a common bamboo species found in Indonesia, and other biomass sources.

10.3 Local availability and familiarity

Bamboo is found in all provinces of Indonesia and covers approximately 2.1 million hectares (FAO 2005). There are around 135 species of bamboo in Indonesia (FAO 2005) either found naturally or cultivated deliberately. In the wild, bamboo is found in protected forests, national parks and nature reserves. As a planted crop, it is found in community forests, village gardens and in company plantations. In Indonesia, households can grow bamboo on areas for other land uses (APL), convertible production forest (HPK), permanent production forest (HP) and protection forest (HL) estates through non-timber forest product utilization permits (IPHHBK), and in certain nature reserve (KSA) and nature conservation (KPA) estates through environmental cooperation agreements. Bamboo is a familiar local plant, and is deeply rooted in Indonesian cultures and traditions as it has been used for centuries. Most farmers have some bamboo plants in their gardens. Indonesians commonly utilize bamboo as an essential material in their daily lives, using it for food, fuelwood for heating and cooking, and as a material for furniture and building. Its strong and flexible woody stems are also used as a construction material. This local familiarity could mean high community acceptance and willingness to participate in bamboo-based bioenergy production.

10.4 Synergy with food production and biodiversity

The production of feedstocks for bioenergy requires land and water. Consequently, bioenergy is often a source of debate because of its potential to impact negatively on food production and biodiversity due to land-use change and competition for resources (Immerzeel et al. 2014). Using bamboo as a feedstock for bioenergy can avoid these conflicts, especially when bamboo is grown on degraded and underutilized land. Bamboo is abundantly available, fast growing, and can grow on degraded and marginal lands or in combination with other crops in forestry or agroforestry systems, thus causing minimum competition for land (Mishra et al. 2014). As a fast-growing species that can develop on degraded lands, it can also establish a habitat for biodiversity, and with only sustainable harvesting of the crop, this habitat can be maintained in perpetuity. Also, increasing the availability of bamboo for bioenergy will help replace the use of fuelwood, thereby reducing pressure on forests. Where other bioenergy crops require replanting after harvesting, bamboo crops are usually ready in 5–12 years and can be harvested systematically each year without removing clumps, thereby ensuring the next 30- to 50-year life cycle (de Carvalho et al. 2013; Banik 2015; Benton 2015). In fact, managing a bamboo stand's age and density with annual thinning—using the derived material as feedstock—can increase bamboo productivity (Jianghua 2001).

10.5 Contribution to livelihood improvement

The agriculture and forestry sectors contribute significantly to Indonesia's economy, supplying nearly 12% of its GDP in 2017 (Bank Indonesia 2018). Thus, these sectors serve as a key driver for economic growth. Around 67% of Indonesia's total land area constitutes forest estate, while approximately 30% is used for agriculture (ADB 2015). In total, 49 million Indonesians, or around 41 percent of its total workforce, are employed in these sectors. Around 25,000 villages in Indonesia are located inside or near forest areas, with around 70% of their populations relying on forest resources for their livelihoods. These village farmers and communities could earn additional income by engaging in the cultivation, management and processing of bamboo for biomass feedstock and other bioenergy enterprises. Bamboo plantations are easy to establish and could be harvested for bioenergy production after three to five years, opening new avenues of income generation and a rapid boost to local economies. Bamboo also requires fewer agricultural inputs compared to other bioenergy crops (Ben-Zhi et al. 2005; Mishra et al. 2014), so its production would be a cost-saving resource for the people. Further, in contrast to estate crop plantations that only offer casual employment (Sinaga 2013), bamboo plantations under active management could also offer high numbers of long-term jobs for local people (Xuhe 2003). Indeed, the diversification of income streams would broaden livelihood options and reduce farmers' vulnerability to crop failure, helping them adapt to the changing climate (Bradshaw et al. 2004). In addition, the electricity generated through bamboo-fired power plants, mainly in regions that lack modern energy sources, could help local communities increase their household earnings by engaging in economic activities, such as running small industries. The bioenergy from bamboo-fired power plants could thus catalyse rural economic activities and provide a basis for the alleviation of poverty.

10.6 Climate action

The land use, land-use change and forestry (LULUCF) sector is a major contributor to Indonesia's GHG emissions, mostly from land-use change and forestry (68%) and agriculture (7%) (WRI 2018). Through its NDC, Indonesia has committed to reducing its GHG emissions by 29% compared to a business-as-usual scenario by 2030, which requires major interventions in the land use sector. Bamboo bioenergy offers a number of opportunities for emissions reductions in this sector. First, it can contribute to reducing emissions by replacing fossil fuel use for energy generation. Second, as a fast-growing species, it can rapidly sequester and store carbon in its biomass (Lou et al. 2010). Its rapid growth rate and high annual post-harvest regrowth make bamboo an excellent plant for carbon sequestration and storage (Lou et al. 2010). Although data on bamboo's carbon storage and sequestration potential in different cultivation systems is limited, several studies around the world have made estimations based on species composition, geographic location, environmental conditions and management practices.

Generally, the carbon density of bamboo forests (ranging from 168.7 to 259.1 t C ha^{-1}) is higher than the global average forest carbon density (86 t C ha^{-1}) (Lou et al. 2010). A study in China reported that a high amount of carbon (106.36 t ha^{-1}) is stored in a typical moso bamboo *(Phyllostachys edulis)* ecosystem (34.3 t ha^{-1} in the aboveground green vegetation and 72.2 t ha^{-1} on the forest floor and soil up to 60 cm in depth) (Zhou and Jiang 2004). In general, the carbon sequestration potential of many bamboo species is comparable to and often higher than that of many fast-growing tree species. For instance, the total carbon stock of five-year-old common bamboo *(Bambusa vulgaris)* is higher (15.53 Mg ha^{-1} $year^{-1}$) than that of fast-growing hardwood species like earleaf acacia *(Acacia auriculiformis)* (10.21 Mg ha^{-1} $year^{-1}$) (Sohel et al. 2015). Similarly, another study showed that in a mixed patch of bamboo species (*B. vulgaris*, *Bambusa balcooa* and *Bambusa cacharensis*) the rate of aboveground carbon sequestration ranged between 18.93 and 23.55 Mg ha^{-1} $year^{-1}$ (Nath and Das 2012).

10.7 Land restoration potential

Land degradation is the temporary or permanent decline in productive capacity of land that will result in negative consequences for agriculture, biodiversity and the environment (IUCN 2015). Further, as it affects people who depend on land-based economic activities, land degradation can lead to increased poverty in developing countries (Barbier and Hochard 2016). Consequently, land restoration has received increased attention as a measure for tackling the land degradation crisis, as reflected in the UN Sustainable Development Goals (SDGs) and in conventions such as the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification (UNCCD) and the Convention on Biological Diversity (CBD). Decades of exploitative land-use practices, such as mining and the drainage and conversion of peatlands and forests for agriculture, have resulted in large areas of degraded lands in Indonesia (Anshari et al. 2010; Margono et al. 2014; Wijaya et al. 2015; Gaveau et al. 2016). According to the "Indonesia Land Degradation Neutrality National Report 2015", there are an estimated 24 million hectares of degraded land in Indonesia (UNCCD 2015). In an attempt to address this problem, Indonesia has taken several measures to restore its degraded lands (UNCCD 2015).

However, the biophysical and legal constraints associated with this land and the high costs of reclamation often challenge restoration efforts (Sayer et al. 2004; Sabogal et al. 2015; Stayi and Lal 2015). The restoration of large areas of degraded lands in Indonesia using biophysical measures will require significant investments in time and money. Though restoration costs are difficult to estimate, as they depend among other things on location, method and level of degradation, literature suggests that restoration costs using forest species can generally exceed USD 2,300 per hectare (Sukhdev et al. 2010). This implies long timeframes for productivity and financial returns, which can make farmers and investors hesitant to engage in restoration. In such cases, one common approach to minimizing costs is to plant fast-growing species that can grow in low fertility soils with minimum management intervention (Yu and Peng 1996). Thus, the ecological properties and economic savings and benefits of bamboo make it a unique plant for land restoration.

Bamboo can grow well in degraded and marginal soils with low fertility, and requires little fertilizer or water in comparison to other traditional sources of biomass (Ben-Zhi et al. 2005; Mishra et al. 2014). This implies that, even with less resource input, bamboo can thrive in severely degraded areas where other native species cannot grow. Further, the extensive fibrous root and rhizome systems, dense foliage, and leafy mulch of bamboo stabilize soil, control soil erosion and retain water (Ben-Zhi et al. 2005). Leaf litter from bamboo adds organic matter to the soil and contributes to the fertility of degraded soil. Further, bamboo does not require significant investments and, once a plantation is established, it can be managed without any special maintenance. As bamboo is fast growing and can be harvested continuously for three to four years without replanting, it would yield more rapid returns on investments, thereby attracting investors and farmers. Smallholder farmers could play a cost-effective role in land restoration, and, since they are already used to cultivating bamboo, it would be easy to apply bamboo to land restoration purposes in Indonesia. As the availability of managed bamboo increases, households would also switch to bamboo slats as a renewable alternative to fuelwood, thus bamboo could also help reduce deforestation. Furthermore, bamboo would help diversify landscapes, providing food and habitat for numerous species of insects, birds and other animals (Lou and Henley 2010). Some bamboo species contain high levels of starch and nutrients that are preferred by some wildlife species (Li et al. 2003; Reid et al. 2004; Song et al. 2011).

Although the use of bamboo for land restoration remains relatively small-scale, several initiatives have shown successful results and high potential for implementation at larger scales (FAO and INBAR 2018). In India, for example, a bamboo-based landscape project which commenced in 1997 has been successful in rehabilitating over 85,000 hectares of degraded lands while supporting thousands of livelihoods (Benton 2014). Several members of the International Network for Bamboo and Rattan (INBAR) are promoting the use of bamboo for land restoration as part of the Bonn Challenge (FAO and INBAR 2018). Recent bamboo-based restoration programmes include the Chinese State Forest Administration's plan to restore 3 million hectares, a plan to restore at least 500,000 hectares in the Philippines, and India's programme to restore around 100,000 hectares (Buckingham 2014). Indonesia could draw lessons from other tropical countries on using bamboo as a restoration species. Its capacity for rapid growth on degraded land with few production inputs, for stabilizing and adding organic matter to soil, and yielding biomass continuously without replanting makes bamboo a unique plant for land restoration in Indonesia.

With proper harvesting and management plans, bamboo plantations established for bioenergy could also help Indonesia to achieve goals signed under initiatives such as the Forest Landscape Restoration (FLR) (Bonn Challenge 2015), the New York Declaration on Forests (2014), and other UN conventions. Using bamboo for the restoration of degraded lands could create ecological and economic benefits for local communities and support the government's climate and development goals. However, bamboo should not be a substitute for native vegetation in restoration efforts, and should only be planted on degraded lands where planting native vegetation is not ecologically feasible.

10.8 Potential challenges

Although bamboo provides many ecological and socioeconomic benefits, there can be several challenges in its cultivation and management for bioenergy production. First, if bamboo plantations are not managed properly, the plant can pose a threat as an invasive species, as it can displace the surrounding native vegetation (O'Connor et al. 2000; Richardson and Canavan 2015). In addition, bamboo monocultures may increase forest cover, but may also simplify forest structure and modify or decrease biological diversity (Xu et al. 2008, 2015). Further, planting bamboo could pose a potential risk to biodiversity and food security if farmers clear-cut native vegetation or convert farmland to bamboo plantations in the pursuit of higher profits (Song et al. 2011). Even though bamboo requires fewer pesticides and fertilizers than other crops, intensive management involving harmful chemicals in the pursuit of higher production could still cause land and water pollution (Mariyono et al. 2018). Like other dedicated bioenergy crops, bamboo may also compete with food crops for land and water if it is grown on agricultural land. Addressing these issues is crucial when considering the suitability of bamboo for bioenergy production.

10.9 Conclusion

This paper discusses the potential of bamboo as a feedstock for bioenergy production and delivering other socioeconomic and environmental benefits in Indonesia. We believe that with proper planning, management and harvesting, bamboo has great potential for use as a feedstock for bioenergy production in Indonesia. Bamboo is abundantly available, familiar to local people, fast-growing, has multiple uses, can rapidly store and sequester carbon, can grow on degraded lands, and has good fuel characteristics for modern bioenergy production. The integration of multi-purpose perennial bamboo crops in energy systems in Indonesia could contribute substantially to achieving renewable energy targets while supporting land restoration objectives by offsetting the high costs involved in meeting the restoration goals of the Bonn Challenge. Yet, there is a dearth of literature on bamboo in the Indonesian context, and, to our knowledge, no studies have been conducted on the social, economic and ecological feasibility of using bamboo for bioenergy. We recommend further studies on the management of bamboo in the country, such as how much bamboo is locally available for bioenergy production, what species are best suited for bioenergy production, the extent to which GHG emissions would be reduced by using bamboo, where potential areas for future plantations are located, and other feasibility studies to explore the potential of bamboo in the country.

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