Sustainable forest management and forest products industry development in Ethiopia

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HIGHLIGHTS

- Development and innovation in the sustainable forest products industry enhances socio-economic growth and the optimization of environmental objectives.
- Land and forest resources are the major basic productive factors for primary and secondary forest products manufacturing.
- Productive factors determine the development and competitiveness of forest products.
- Collective actions and inclusiveness are important in large-scale tree planting programmes for accelerated impact.
- A sustainable landscape approach is an effective tool for sustainable forest management and innovative forest products industry development.

SUMMARY

The objective of this study was to examine existing knowledge on forest products development and to promote sustainable forest management in Ethiopia. Furthermore, the paper aimed to assess the development and status of Ethiopia's forest products industry in terms of resource base, manufacturing and marketing. It was found that the current annual fuelwood consumption is about 133M m^3, with 90% of cooking energy obtained from woody biomass. Wood consumption for primary and secondary forest products manufacturing is expected to increase from the current 112M m^3 to 158M m^3 by 2033. This review reveals that the development and innovation of a sustainable forest products industry in Ethiopia should balance the production and ecological functions of forest resources. To meet Ethiopia's primary and secondary forest products needs, it is recommended that a clear policy framework be advanced and promoted, including wood technology, forest science and education, silviculture, and post-plantation management practices.

Keywords: forest industry, forest products, productive factors, collective actions, tree planting, sustainable forest management

Développement de l'industrie des produits forestiers et de la gestion forestière durables en Ethiopie

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L'objectif de cette étude a été d'analyser les connaissances du développement des produits forestiers et de promouvoir une gestion forestière durable en Ethiopie. Le papier s'efforce également d'évaluer le développement et le bilan de l'industrie des produits forestiers éthiopienne, quant à leur base de ressources, leur fabrication et leur commercialisation. Il a décelé que la consommation annuelle actuelle de bois de chauffage approche des 132.9M m^3, avec 90% de l'énergie de cuisine provenant encore de la biomasse du bois. Le bois et sa consommation ont une augmentation prévue de 112M m^3 actuellement, à 158M m^3 d'ici 2033, pour la fabrication primaire et secondaire de produits forestiers. Ce papier révèle que le développement et l'innovation d'une industrie durable des produits forestiers en Ethiopie devrait équilibrer la production avec les fonctions écologiques des ressources forestières. Il est recommandé qu'un cadre de politique clair, incluant la technologie du bois, la science et l'éducation de la foresterie, la sylviculture et les pratiques de gestion suivant la plantation devraient être avancés et promues, afin de satisfaire les besoins de l'Ethiopie en produits forestiers primaires et secondaires.

Gestión forestal sostenible y desarrollo de la industria de productos forestales en Etiopía

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El objetivo de este estudio fue analizar los conocimientos sobre el desarrollo de productos forestales y promover la gestión forestal sostenible en Etiopía. Además, el artículo se propuso evaluar el desarrollo y la situación de la industria etíope de productos forestales en lo que respecta a la base de recursos, la fabricación y la comercialización. Se descubrió que el consumo anual actual de leña es de unos 132,9 millones de m^3, y que el 90% del suministro de energía para cocinar sigue procediendo de biomasa de madera. Se prevé que el consumo de madera pase de los 112 millones de m^3 actuales a 158 millones de m^3 en 2033 para la fabricación de productos forestales primarios y secundarios. Este artículo revela que el desarrollo y la innovación de una industria sostenible de productos forestales en Etiopía debe equilibrar las funciones de producción y ecológicas de los recursos forestales. Se recomienda desarrollar y promover un marco de políticas claras que comprendan la tecnología de la madera, la ciencia y la educación forestales, la silvicultura y las prácticas de manejo posteriores a la plantación, con el fin de satisfacer las necesidades de Etiopía de productos forestales primarios y secundarios.

INTRODUCTION

Ethiopia started following a Climate Resilient Green Economy (CRGE) growth path about a decade ago with a vision to achieve middle-income status by the year 2025 (FDRE 2012). The strategy has been broadly aimed at three major economic sectors: forests, livestock and energy, with industry and transportation being the major energy consumers in the sustainability interwoven fabric. While forests serve as a carbon sink, livestock, along with agriculture, industry and transportation sectors are the main sources of carbon emissions. This has been a challenge for the country because it requires tackling multi-objective socioeconomic and environmental optimization. The CRGE has been utilizing forests (e.g., forest conservation and restoration) as tools for climate change mitigation and rural economic development in a sustainable landscape approach (MEFCC 2016, 2018a, 2018b).

Indeed, forest resources have been serving a dominant productive purpose and playing a vital role in meeting the demand for wood and wood-based products (hereafter referred to as forest products) by society in general. The development, management, utilization, and innovation of forest resources should incorporate the broader aspects of human wellbeing in order to achieve the global sustainable development goals (MEFCC 2016, Rawat 2017, Badea and Apostol 2020). Achieving these global goals necessitates the simultaneous balancing of ecosystem services and productive goals, which becomes a demanding and complex aim. It specifically needs adequate policy and proactive interventions to meet the increasing demand for forest products by society in general, and particularly by industries, by assuring environmental and social sustainability. This in turn requires valuation of the significance of forests in environmental conservation in Ethiopia as well as their sustainable management and utilization for productive purposes such as for energy, timber, furniture, pulp and paper, and construction. To foster sustainable and competitive development and management in the forest sector, there is a need not only for a holistic approach in keeping the supply and demand balance for wood, but also a pressing need for enhancing the effectiveness of supporting sectors and potential innovations, in order to reduce the dependency on imported forest products and raw materials (MEFCC 2018a, MEFCC 2018b). Effective development of the value chain spanning from forests to the consumer and innovation of the forest products business model helps to mitigate social and environmental issues by creating significant job opportunities, in addition to strengthening the capacity of the forest products sector (Hansen 2016). In this vein, the forest products sector has the potential to nationally contribute to the fulfilment of about a third of the seventeen sustainable development goals (SDGs or the Global Goals) towards which Ethiopia is committed (FDRE 2017).

Currently, there is a high demand for both productive use and environmental services of forest resources in Ethiopia (Kelbessa and Girma 2011, MEFCC 2017). Natural and planted forests sequester carbon and help to mitigate climate change. Additionally, planted forests help to restore native biodiversity and improve soil quality (Indufor 2016). This, in turn, broadly reduces soil degradation and the siltation in dams, thereby contributing to the sustainability of power generation, efforts in climate change adaptation and mitigation (MEFCC 2016). The demand for forest products comes from the need to sustain the existing demand for energy, furniture and construction. Other demands come from consumable goods such as paper, as well as from the sophistication of consumers' desire for more and improved forest products as a result of elevated living conditions emanating from fast economic growth. Ethiopian forest resources can render effective ecosystem services that balance productive services only if they are competitive enough at a global scale.

Although it has been implicit, the CRGE and associated development paths are being planned and implemented envisioning the natural-resources-based view (NRBV) of competitive advantages. The NRBV of competitive advantages is composed of three interconnected strategies: pollution prevention, product stewardship, and sustainable development as described first by Hart (1995) and strengthened later on by Hart and Dowell (2011). The Grand Ethiopian Renaissance Dam (GERD), the large-scale sugar mills, industrial parks, the planned Public-Private-Partnership in wood-based industries and even the country's ambition to participate in global carbon finance and trade are good indicators of the NRBV nature of current development endeavours (Hassan 2008, Zhang *et al.* 2018). Hence, the competitiveness pillars are natural resources and related productive factors, with an intention to build other advanced competencies with time through knowledge, skill and technology transfer. However, well-documented and systematic studies on the theoretical backing of NRBV endeavour, including forest products development and its application in Ethiopia, are lacking. Even the majority of related works, among the few available, are inaccessible, being archived in institutional and private office repositories. Hence, it is necessary to systematically search, retrieve, review, assess and synthesize useful information on the sustainable development of forest resources and industry with emphasis on productive factors so that systematized knowledge and decision support literature is available.

This review paper, therefore, delves into the forestry sector and assesses existing productive factor conditions in the Ethiopian forest products manufacturing sector, and the value that can be delivered to meet the demand for forest products and energy with due consideration to the three pillars of sustainability (Schaan and Anderson 2002).

A sustainable and competitive supply of forest products in a given nation is determined by both basic and advanced productive factors of the forest industry. The basic productive factors are endowments with suitable land resources, suitable climate, and accessibility of locations and demographics, while advanced ones are developed infrastructures-including information communication technology, the availability of sophisticated skills and research facilities. Advanced productive factors are built upon the basic ones and they are usually accumulated through persistent investment by government, individuals and industries (Sasatani 2009). This situation is reviewed in this study in light of the three pillars of sustainability and the following interlinked dimensions of competitiveness of the Ethiopian forest products industry: 1) productive factors determining the development of forest products industry, 2) ecological and socioeconomics of Ethiopian forest products resources development, 3) wood production and consumption, and 4) the state and development of the sustainable and competitive forest products industry in Ethiopia.

METHODOLOGY

The study was carried out as a systematic review that yielded and integrated an overview of the Ethiopian forest products industry. First, a lookup Table (Table 1) was prepared so that the review systematically incorporated ecological, social and environmental dimensions. The following list of keywords was also prepared for the literature review: forest land, forest resources, farm trees, woodlot, plantation, natural forest, timber, fuelwood, charcoal, roundwood, lumber, plywood, particleboard, Medium Density Fibreboard (MDF), pulp and paper, furniture and joinery products.

Two sources of literature were used: grey literature (archived from government and private office repositories) and publication databases. The search for grey literature was achieved through a form of snowballing in which identified key resource persons were asked to provide the literature available in their archives. Thereafter, they were asked to provide information on who else to contact for similar or additional information.

The literature search used combinations of the lookup table, keywords and the following list of databases:

- African Journals Online
- AGRICOLA
- AGRIS
- BioOne
- EBSCO
- EconBiz
- IngentaConnect
- Google Scholar
- Mendeley
- ResearchGate
- Scopus
- SpringerLink

First, keywords and abstracts of the literature obtained in the databases were matched with the keywords of this review. The full-text publication was downloaded for those keywords, which obtained a better match. Thereafter, the documents were visually scanned, thoroughly read, summarized, synthesized and incorporated into the systemic review. The information obtained in grey literature was processed similarly and integrated into the systemic review.

PRODUCTIVE FACTORS DETERMINING THE DEVELOPMENT AND COMPETITIVENESS OF FOREST PRODUCTS MANUFACTURING IN ETHIOPIA

Primary forest products are an output from the direct conversion of timber and include household and industrial commodities such as logs, fuelwood, charcoal, construction poles for structures and scaffolding, utility poles for transmission and distribution of electric power, lumber, plywood, MDF, pulp and paper (UN-FAO 2020). Secondary forest products are those which are further processed or value-added and include furniture and joinery products that use the primary products as inputs or raw materials as described by Lähtinen (2007), and Sathre and Gustavsson (2009). The factors determining the primary forest industries are generally land resources, including infrastructure, cost of energy, cost and availability of both rural and urban labour, labour productivity and technology. A detailed list of the basic factors includes natural forest area and its per capita allocation, accessibility of the natural forest area, overall forest stock, cost of export, rural land area, rural population density, rural labour availability, land value, current plantation area, illegal log extraction and processing, electric and gasoline price. The advanced factors include public and industrial research, innovation, technical and managerial efficiency, and environmental sustainability (Hart 1995, Sasatani 2009). These factors are commonly assessed in a clustered approach in relation to the upstream forest products industries as the demand comes from most of them, except fuelwood and charcoal. Nevertheless, research capability along with advanced skill and knowledge are enablers of innovation that create a competitive edge, when basic factors may face multi-faceted challenges. The capability has been building up for the last 50 years in forestry research and advanced training which has progressively evolved from endeavours that depended on foreign aid to a self-sufficient system (Tadesse *et al*. 2012, Dessie 2013).

Currently, there is one national Forestry and Environment Research Institute overseeing seven branches in various parts of the country, four universities with College of Forestry (one of them offers programmes at M.Sc. and Ph.D. levels), and one newly opened Ethiopian Technical University with M.Sc. level programme in Wood Technology. Generally, forestry courses are offered in Ethiopia at more than thirty public universities under educational programmes in natural resources.

TABLE 1 *Lookup table to integrate ecological, social and economic dimensions of the vertically integrated forest products industry*

Common keywords	Aspects of the Vertically Integrated Sustainable Forest Products Industry in Ethiopia for Keywords Search Strategy									
	Aspects of the Forest Resources Base for Keywords					Aspects of the Forest Products Industry				
	Types of forests or timber species	**Human activities**	**Ecological**	**Social**	**Economic**	**Commodity**	**Human activities**	**Ecological**	**Social**	**Economic**
Ethiopia	Trees on farms	Tree planting	Forest land	Source of food	Income	Fuelwood and charcoal	Transport	Wastes	Employment	Revenue
East Africa	Woodlots	Stand management	Forest cover	Source of animal feed	Cost	Timber	Storage	Emissions	Work Environment	Cost
Sub-Saharan Africa	Community forests	Harvesting	Deforestation	Source of medicine	Yield	Round wood	Sawmilling	Life Cycle Assessment	Satisfaction	Volume of production
	Plantations	Education	Soil degradation	Livelihood	Valuation	Sawnwood	Peeling		Preferences	Value of production
	Natural forests	Training	Impact on water resources	Cultural norms	Competitiveness	Lumber	Production		Cultural norms	Value chain
	Cupressus lusitanica	Research	Impact on biodiversity		Investment	Veneer	Distribution			Quality of products
	Cordia africana	Competencies	Carbon sequestration			Plywood	Selling			Competitiveness
	Pine species	Innovation	Emissions			Particleboard	Purchasing			Investment
	Eucalyptus species					Fibreboard	Consumption			
						Pulp	Education			
						Paper	Training			
						Furniture	Research			
						Construction wood	Competencies			
						Joinery products	Innovation			

Land and forest resources as the major basic productive factors for primary forest products manufacturing

The rural land administration and land use proclamation No. 456/2005 regulates acquisition and use of rural land, rural land measurement, registration and the way certificates are held, tenure of rural land use rights, transfer of rural land use rights, distribution of rural land, obligations of rural land users, size of rural land holding, land consolidation mechanisms and rural land-use restrictions (FDRE 2005). However, the clear demarcation and delineation of agricultural land, forest land and land serving other objectives have not been finalized. These have been challenges impeding the full enforcement of the proclamation and favoured the continuation of the arbitrary conversion of land use classes. The National Forest Inventory (NFI) classified given land as a 'forest' in line with the reporting of the Global Forest Resources Assessment (FRA) and adopts the definition describing forest as a 'Land with a tree canopy cover that is greater or equal to 10%, on an area of 0.5 ha and with an average tree height of 5 meters. The woodland area is estimated to cover a total of 57.5M ha, corresponding to 49.9% of the total land area (MEFCC 2018). The recent definition of forest that is being adopted by the Environment, Forest and Climate Change Commission (EFCCC) of Ethiopia reclassified about 10% of the woodland as forest, which is comprised of 'Land spanning at least 0.5 ha that is covered by trees (including bamboo) with a minimum width of 20 meters or not more than two-thirds of its length, attaining a height of at least 2 meters and a canopy cover of at least 20% or trees with the potential to reach these thresholds *in situ* in due course. Recently, Ethiopia's National Forest Inventory (MEFCC 2018), which lasted from 2013–2017, regrouped the classes into five biomes as Acacia-Commiphora woodland, Combretum-Terminalia woodland, Dry Afromontane, Moist Afromontane forests and others. Majority of the biomes are estimated to be located in cultivated lands, e.g., Combretum-Terminalia woodland (42.5%), Dry Afromontane (61.6%) and Moist Afromontane forests (48.2%) while the majority of Acacia-Commiphora (73.1%) is located in uncultivated woodland. Naturally regenerated forests are higher in the Moist Afromontane biome (26.3%) followed by Combretum-Terminalia (8.3%), Dry Afromontane (4.4%) and Acacia-Commiphora (1.4%). Similarly, forest plantation was also found to be higher in the Moist Afromontane biome (1.3%), with less than 1% found in other biomes (MEFCC 2018).

The country's current forest area is estimated to be about 20.08M ha, based on the new definition of forests that significantly increased the forest cover of Ethiopia (more than 3-fold increased, i.e., 15.5%) (Indufor 2016, MEFCC 2016). The majority of the forest area is covered with natural forests (16.22M ha) followed by woodlands (2.38M ha), woodlots (0.82M ha), shrublands (0.47M ha) and industrial plantations (0.19M ha). Most of the plantations are state-owned, while, woodlots and smallholder plantations are private holdings (Indufor 2016). *Cordia africana* (Wanza), *Pouteria adolfi-friederci*, *Hagenia abyssinica*, *Olea* spp., *Juniperus procera*, *Podocarpus falcatus*, *Mimusops kummel*, *Prunus africana*, *Syzygium guineense* and *Warburgia ugandensis* form the natural forests (Bekele-Tessemma 2007, Kelbessa and Girma 2011, Dessalegn *et al*. 2012, Indufor 2016), while industrial plantations consisting of exotic species such as *Cuperessus lusitanica, Pinus radiata, Pinus patula, Eucalyptus*, *Acacia decurrens*, *Grevillea robusta* are mostly used for roadside plantation. *Eucalyptus* species are found both in industrial plantations and woodlots (Gil *et al*. 2010, Indufor 2016). About 78% of industrial plantations are found in Oromia; Southern Nations, Nationalities and People's Regions (SNNPRs); and Amhara comprising *Eucalyptus* species (60%), *Cupressus lusitanica* (18%), *Grevillea robusta* (2%) and *Pinus patula* (1%). The mixed plantations of *Eucalyptus* species and *Cupressus lusitanica* stands account for 6% of industrial plantations while other mixed type forests account for 13%. Farmers are involved in the expansion of small-scale private plantations, woodlots and agroforestry in the highlands (Dessalegn *et al*. 2012, Indufor 2016).

Table 2 indicates that *Eucalyptus* species account for about 60% of commercially planted timber species within which *Eucalyptus globulus* accounts for about 40% of the overall share. *Cupressus lusitanica*, which is the most important exotic and introduced softwood timber species in Ethiopia, accounts for more than 31%. Table 2 indicates that more than 75% of all plantations were 20 or more years old. The Oromia Forest and Wild Life Enterprise (OFWE), which is one of the two largest government-owned forest enterprises in Ethiopia, has been active in establishing new plantations on forestlands since its establishment in 2009. The majority of *Eucalyptus* species stands have been harvested and now are growing in the third cycle of coppicing. However, the stands of *Cupressus lusitanica* and pine species are non-coppicing. After harvesting, they were replaced with new planting. As a result, the proportion of old stands of *Cupressus lusitanica* and pine species have been declining while the share of younger stands is increasing. Data obtained from the Amhara Forest Enterprise (AFE), which is the second largest government-owned forest enterprise in Ethiopia, indicate similar compositions in terms of species and distribution of age groups of planted timber species. However, indigenous timber species such as *Cordia africana* and *Hagenia abyssinica* are being planted mainly for conservation purposes, in both cases of OFWE and AFE.

The Ethiopian Proclamation on Forest Development, Conservation and Utilization No. 1065/2018 issued in 2018 classifies forests based on ownership as private, community (a forest developed, conserved, utilized and administered by the community), associations' (a forest developed, conserved, utilized and administered by associations) and state forests. All the natural forests and the majority of plantations are owned by the state (FDRE 2019a, 2019b) which are classified as productive, protected and preserved. Plantations are classified as productive and are also accessible to be utilized for the extraction of forest products. Natural forests are classified either as protected or preserved, hence they are not accessible for utilization. It is prohibited by the proclamation to utilize preserved forests, while only planted trees at the peripheries of protected forests can be utilized by local communities for their own consumption. Nevertheless, such regulations have

TABLE 2 *The composition of planted indigenous, exotic and introduced timber species in terms of species and age groups in the Oromia Region of Ethiopia based on data obtained from the Oromia Forest and Wild Life Enterprise (OFWE) in 2017*

Planted Species	Percentages distribution of each of the individual planted species for each age group			Total [%]	Percentage share of each of the timber species in each of the age groups from the total planted species			Total [%]
	>20 [%]	11–20 [%]	1–10 [%]		>20 [%]	11–20 [%]	1–10 [%]	
Eucalyptus globulus	92.42	2.74	4.84	100	36.5	1.1	1.9	39.5
Eucalyptus camaldulensis	75.43	4.97	19.6	100	6.59	0.43	1.71	8.73
Eucalyptus saligna	89.2	7.66	3.15	100	1.45	0.12	0.05	1.63
Eucalyptus grandis	75.47	5.35	19.18	100	1.19	0.08	0.3	1.58
Eucalyptus citriodora	84.11	15.89	0	100	0.12	0.02	0	0.14
Eucalyptus viminalis	0	100	0	100	0	0	0	0
Eucalyptus species	70.1	7.06	22.84	100	5.84	0.59	1.9	8.34
Cordia africana	0	0	100	100	0	0	0.01	0.01
Hagenia abyssinica	2.33	10.49	87.19	100	0.02	0.08	0.7	0.8
Olea welwitschii	0	0	100	100	0	0	0.01	0.01
Olea africana	81.23	0	18.77	100	0	0	0	0.01
Acacia decurrence	0	0	100	100	0	0	0.07	0.07
Grevillea robusta	29.74	15.3	54.96	100	0.34	0.17	0.62	1.13
Other Acacia species	38.81	0	61.19	100	0.02	0	0.03	0.04
Podocarpus falcatus	93.27	0.98	5.75	100	0.12	0	0.01	0.13
Cupressus lusitanica	63.17	17.18	19.65	100	20.03	5.45	6.23	31.71
Juniperus procera	54.32	21.57	24.11	100	1.41	0.56	0.62	2.59
Pinus patula	54.11	21.22	24.67	100	1.41	0.55	0.64	2.6
Pinus radiata	23.27	43.04	33.69	100	0.03	0.06	0.05	0.15
Casuarina equisetifolia	74.77	5.85	19.38	100	0.04	0	0.01	0.05
Softwood and Hardwood mixed species	55.55	19.38	25.07	100	0.42	0.15	0.19	0.75
Total					75.53	9.36	15.05	100

never been effectively implemented and illegal logging has been rampant in protected and preserved forest resources. For instance, the Forest Sector Review showed that about a quarter of the sources for roundwood and fuelwood supply were not traceable in 2013, implying a probable illegal extraction for which there is no government record (MEFCC 2017). The same review indicates only 7% of the roundwood came from the plantation and the dominant source was also assumed to be woodlots (more than 4.8%). The 25% unspecified source is even projected to increase its share to more than 33% of the overall national supply of wood by the year 2033, with a two-fold increase in the volume of wood supply.

ECOLOGICAL AND SOCIOECONOMIC DIMENSIONS OF ETHIOPIAN FOREST PRODUCTS RESOURCES BASE DEVELOPMENT

Productive factors that are crucial to the sustainable forest products industry need to be used and transformed as capabilities by effective activities in forest resources development, synergistic conservation, sustainable management, sound governance and supportive institutions in order to make competitiveness a reliable outcome (Hinerhuber 2013). Each of these factors is assessed in this section with respect to the Ethiopian situation.

Forest conservation and management

Demand for fuelwood, charcoal, and industrial wood is currently being met in an unsustainable manner by supplies sourced from forests and woodlands. In Ethiopia, deforestation and degradation have been significant (Neumann 2008, Limenih and Kassa 2014), with the conversion of land for timber, fuelwood and charcoal production being a major cause (Admassie 2001, Dessalegn 2001, Bekele 2011, Eshetu 2014, Kebede and Dejene 2019). For example, the forest sector review of MEFCC (2017) estimates annual rates of deforestation in high forests and woodlands as 2.2 and 2.1%, respectively. The country does not yet have officially demarcated land use classes, though it is legally prohibited to change forestland into agricultural land. Against this backdrop, the impact of a high rate of deforestation has been observed in terms of shrinking forest cover. Forest cover was estimated to be 40% of the total land area in the 1900s, and recent FRA based sources indicate a forest cover of about 15.5% of the total land area (Indufor 2016, MEFCC 2018). The depletion of forest resources was mainly due to population growth and poverty perpetuating the vicious circle of overexploitation for fuelwood, charcoal, agriculture, rural settlement and expansion of grazing land (Kilawe and Habimana 2016, MEFCC 2018b). The drastic shrinking extent of the country's forest cover, if allowed to continue unabated, presents a severe challenge for sustainable management and utilization of forest resources. Therefore, the forestry sector has been unable to adequately fulfil the ever-increasing demand of the wood industry for timber. As a result, the forest products value chain has been badly impacted, resulting in an increase in forest product imports, particularly from the far East. Hence, priority should be given to creating conducive conditions to develop plantations, woodlots and expand forest land resources, which are the major components of the basic productive factors. The forestry sector and sustainable forest products industry development help to enhance the contribution of the sector to the GDP via maximizing the activities on sustainable industrial plantations, creation of job opportunities and value addition (Nune *et al*. 2013). Moreover, sustainable development will motivate public involvement and promote strong communities-to-private sector linkages. As a result, there will be increased investment in the sector's development and innovation (Kilawe and Habimana 2016).

The New York declaration in 2014 is committed to provide financial aid to the rehabilitation of degraded forests (UN 2014). Ethiopia is the signatory of international conventions, e.g., the Convention on Biological Diversity (CBD), the UN Convention to Combat Desertification (UNCCD), and the UN Framework Convention on Climate Change (UNFCCC) and the Convention on International Trade in Endangered Species (CITES). The commitments help in biodiversity conservation and climate change problems (Dessalegn 2001). Our observations indicate that the government is committed to increase forest cover, and has started several schemes, including afforestation and reforestation programmes. The recent national flagship initiatives of the Green Legacy, if allowed to continue with the current collective mass actions and sustainable landscape approach of natural resources development, would result in an accelerated increase in the country's forest cover. However, post-planting management, appropriate forestry and silviculture practices are needed to take care of planted seedlings. To make such initiatives competitive and sustainable, the end results of such activities should include not only timber values but also non-timber values and carbon credits (Sutcliffe *et al*. 2012). Additionally, the initiatives can tap provisions of incentives and benefits extended to the private sector that is involved in forest management and development. The provisions of incentives are articulated in the recent forest proclamation No. 1065/2018 (FDRE 2019). Such a process will set a momentum for the development of sustainable forest products manufacturing, thereby contributing to the economy.

Collective actions and large-scale tree planting for forest products resources development

Participatory collective actions in community and farm woodlots can bring about accelerated forest products resources-based development for conservation and productive purposes (Cernea 1990, Arnold 2001, Wale and Nayak 2020). In light of collective actions, initiatives such as mass mobilization and mass actions have been taking place in the development of urban forestry and woodlots. Collective or synchronized mass actions are often transformational and helpful for countries such as Ethiopia aspiring for accelerated forest cover change. It is imperative to plant trees on community lands, private lands, streets, private compounds, home gardens and other places, as part of a joint programme. The outcome becomes heterogeneous but resilient to withstand anthropogenic and environmental effects (Doss and Meinzen-Dick 2015).

Planting mono crops such as *Eucalyptus* is not a complete and sustainable solution; however, mono cropping for specific purposes may be appropriate for private forestry companies. To date, the collective actions in community forest management are scattered and localized. Collective actions are influenced by several social (e.g., inclusiveness, human capital, skills, decision making) and ecological (e.g., structure, size, boundaries) factors as described by Doss and Meinzen-Dick (2015). Hence, it is the responsibility of civil society along with the government to promote and sustain green movements (e.g., the green legacy initiative of the government of Ethiopia [GoE] in tree planting and tending) and leave a tree footprint for the future generation and for the sake of environmental sustainability.

The effect of collective actions on tree planting decisions of individual households is often an interesting theme. Tree planting decisions at the farm level, e.g., were considered as a land management strategy in typical farming and land degraded areas of the Mojdo watershed in Ethiopia (Gessesse *et al*. 2016). The tree planting decision was influenced by various factors (e.g., biophysical, institutional, socioeconomic and household-level). At the household level, factors such as the household size, availability of labour, education, livestock holding and the land tenure system have influenced tree planting decisions (Gebreegziabher *et al*. 2010, Gessesse *et al*. 2016, Mekonnen and Bluffstone 2017). In particular, Mekonnen and Bluffstone (2017) argue that incentives are needed for private tree planting at a local level (e.g., farm, household, community) to reduce pressure on forests. In many African and Asian countries (e.g., Malawi, Kenya, Ethiopia, Nepal, Bangladesh, Indonesia) tree planting is initiated to enhance the household income and meet the domestic needs of wood, such as for fuelwood and helps to support a sustainable forest products industry. There was also a provision for incentives and bonuses for farmers who grow trees. Collective actions in tree planting are useful to supply the raw materials for primary and secondary forest products manufacturing and support the forest sector development.

Trees have meant a lot for farmers in low income developing countries to meet the subsistence requirements and conservation. Such practices of tree planting at the household level, improve the livelihoods of smallholder farmers and provide food security (Gebreegziabher *et al*. 2010). Planting of trees at the local level helps to meet the demand for wood as a raw material that is used to manufacture various products, e.g., primary and secondary forest products. Alternatively, it helps to create jobs and secures livelihoods in rural areas. It also helps the government with regard to managing and maintaining new plantations. Gebreegziabher *et al*. (2010) further pointed out that farmers had various needs and preferences while planting trees on farms, such as income, food, fuelwood and fodder. For example, even in the case of the controversial *Eucalyptus* species, *Eucalyptus*-based agroforestry systems could become more relevant in waterlogged areas to improve household income, food security and meet the demand for wood without nutrient depletion and competition against the production of food crops (Kidanu 2004). Consequently, the collective choice and mass planting of the species can be tolerated. However, the invasive and controversial nature of the species discussed in Gil *et al*. (2010) needs to be taken into consideration, in such instances.

The successful collective management of woodlots in Ethiopia was demonstrated by Gebremedhin *et al*. (2003). The same report concludes that collective actions are more beneficial and effective at a local level for community resources management; it should also be scaled up at a larger scale and so on. Moreover, the collective actions promote tree species diversity and ecological resiliency (Mekonnen and Bluffstone 2017).

Collective actions and tree planting are important considerations for fuelwood, sustainable land management, forests, soil and water conservation in a sustainable landscape approach, thereby reconciling conflicting and competing land uses (Sayer *et al*. 2013, Turly 2016). This is because they contribute to rapidly increasing forest cover in a short period of time and provide critical factors of production for sustainable forest products manufacturing and innovation, while also ensuring environmental sustainability. To this end, inclusiveness and incentive mechanisms need to be requirements of the collective actions in order to promote tree planting and support the green legacy initiative of the GoE as described in Bass *et al*. (2013). It is important that the impact of collective actions in the green legacy is perceived both in terms of environmental services and productive uses (Sutcliffe 2012). It is also important to bear in mind the fact that special processing technologies are needed to handle the heterogeneous materials resulting from mass tree planting in the complex landscape, as well as from growing highly mixed tree species.

Forest degradation and its interplay with policy and governance

The development of the forestry sector and policy in Ethiopia has been exhibiting a dynamic process of institutionalization and deinstitutionalization. It has been co-shaped by a complex interplay of structural factors such as regime changes, national political orientation and economic priorities, environmental calamities and the dynamics in the global forest-related discourses (Weldesillasie and Gurmu 2001, Heckett and Aklilu 2009, Ayana *et al*. 2013). The current development and environmental policies have been formulated in order to adequately create a new role for stakeholders, diversify management systems, upgrade the value chain of products and services, integrate forest conservation measures in order to promote an appropriate framework for the forestry sector. However, laws and policies have been less enforced, and tough struggles persisted that impeded the maintenance of international standards and guiding principles. Shortcomings were related mainly to the coordination of the forest sector regionally within the country, and nationally. Impediments in other economic and social development objectives, delay in the reform of public forest administrations, inadequate participation of stakeholders, weak assistance to forest owners and local communities, and lack of compensation for social and environmental services of forests are some among the extended list of shortcomings (Kohler and Schmithüsen 2004, Sandewall *et al*. 2015).

In the past, Ethiopian forest resource governance was criticized for terminating the rights of common on forest resources. As a result, illicit felling of trees occurred in protected areas and large forest areas were set on fire, which destroyed the forests and adversely affected wildlife and biodiversity. The resettlement, collectivization and after-famine villagization carried out during 1984–85 to transform rural life and construction of infrastructure caused devastating effects on forest resources and enhanced soil erosion (Dessalegn 2001, Mulugeta and Woldesemait 2011). The causes-effects, forest cover change and its drivers, implications and remedial measures are depicted in Table 3. The wicked land reform, land distribution and re-distribution had discouraged farmers from investing in land and conservation. Furthermore, expansion of state farms and resettlement, which has been considered to be a major cause of deforestation, was a prime strategy of the Derg regime to ensure food security and sparsely distribute the population in order to ease the pressure on densely populated areas (Dessalegn 2001). Consequently, the rate of annual degradation and net forest loss has remained high at about 5.2% (Limenih and Kassa 2014). Moreover, the degradation of forest resources inflicted a negative impact on environmental services, biodiversity, human wellbeing, the effectiveness of sustainable forest products manufacturing and innovation in Ethiopia.

A large number of problems were faced by farmers during turbulent transition periods. As a result, spontaneous and anarchic destruction of forests took place, such as encroachment on forest boundaries, demolishing of bunds and terraces, setting fire to forests and national parks, illegal harvesting from plantations, and uprooting of young seedlings and sapling from plantation areas (Eshetu 2014). Ultimately, about 60% of the natural capital was destroyed during the transition period (1991–1992) by farmers and others, while national parks and game reserves were also severely damaged (Dessalegn 2001).

TABLE 3 *Key drivers of forest cover change, implications and their remedial measures in Ethiopia*

SI	Attributes	Changes	Detrimental Implications on Forests	Remedial measures
1	Regime change/ transition of power	Deforestation, forest degradation, conversion to agriculture land	Forest degradation, land use change	• Forest conservation and management • Institutional arrangements, legal regulations, and motivational tools • Incentives, afforestation and reforestation programme • Nurseries and plantation schemes • Forestry development, logging, sawmills, wood based enterprises and wood technology • Promotion of agroforestry and community forestry • Collective actions and tree planting • Advocacy, training and capacity building programmes • Soil and water conservation practices • Enrichment plantation, rehabilitation of degraded lands and grazing control • Experienced and skill forest administration • Involvement of local communities, • Human wellbeing and a good quality of life, • Jobs and enhancement of livelihoods, • Awards and rewards
2	Institutional changes	Deforestation, forest degradation, conversion to agriculture land	Forest degradation, wicked management	
3	No consideration of communities	Deforestation, forest degradation, conversion to agriculture land	Forest degradation, over exploitation, loss of biodiversity, grazing in forest areas, conversion to agriculture land	
4	Population growth and poverty	Deforestation, forest degradation, conversion to agriculture land, conversion to other land uses	Pressure on forest resources, fuelwood and fodder exploitation, increased demand for wood and land, depletion of resources	
5	Fuelwood collection and charcoal production	Deforestation, forest degradation	Degradation of forest resources, soil erosion and floods, reduction in aesthetic value, biodiversity loss, depletion of water	
6	Large scale conversion of forests to agricultural land	Conversion to agriculture land	Forest degradation, encroachment of land, land cover change	
7	Settlement	Conversion to other land uses	Land cover change, diminish of forests	
8	Calamities such as forest fire and epidemics	Forest degradation, conversion to other land uses	Depletion of forest resources, forest degradation, habitat destruction and effects on wildlife	

Note: The causes-effects, forest cover change and its drivers, implications and remedial measures were identified and analysed based on the assessment of current knowledge base (Gebrehiwot *et al.* 2014, Othow *et al*. 2017, Belayneh *et al.* 2018, Gifawessen *et al*. 2018, Solomon *et al*. 2018, Alme and Amsalu 2020, Ango *et al.* 2020, Badesso *et al*. 2020).

There has been a perceptible lack of appreciation of the value of trees to rural communities which has been a prime cause for the series of failures (Lacuna-Richman 2012). The inspiration, motivation, consent, collective actions and sustenance of the enlightened participation of local communities is vital for the development of the sustainable forestry sector and the forest products industry. Most importantly, a fair and equitable sharing of benefits is crucial for the creation of lasting job opportunities, rural development and livelihood enhancement (Rawat 2017). Persistent effort shall be exerted to trigger and sustain remarkable changes by developing synergy among different stakeholders, including local communities, for the attainment of a competitive forest products industry, environmental sustainability and socio-economic goals (Sutcliffe *et al*. 2012, Nijnik *et al*. 2019).

Institutional arrangements

The frequent changes in regimes, institutions and revisions of laws have had detrimental effects on forest resources management and the sustainable forest products industry. Additionally, the forest sector has been lacking critical resources as compared to the agriculture sector, due to increased priority allocated to agriculture and food security (Weldesilassie and Gurmu 2001, Ayana *et al*. 2013). Previously, the economic values of forests have not been given due importance (Nune *et al*. 2013, Kilawe and Habimana 2016). It may be worth considering the hierarchical system of forest management of Kenya as described by Nyangena (2008) as a good example of delivering effective technical, extension and management services. To date, there are no dedicated forest rangers and forest extension agents to deliver forestry services in Ethiopia (MEFCC 2016). There is a need for a smart structural organization in the forestry sector in which competing objectives are harmonized and synergized. Organizational innovation in the forest sector is indispensable for accelerated transformation. In this regard, sustainable forest management practices and forest product quadruple innovation helices aid in the development and transformation of sustainable forest product manufacturing industries and innovation. In such organizational innovation helices, the federal and regional governments can forge effective partnerships with each other and with the Ethiopian Environment and Forest Research Institute, academia (research universities) and the forest industries (Ollonqvist 2011, Ollonqvist *et al*. 2011, Weiss 2011). Generally, the partnership helps to develop a sustainable industrial development clustered platform for the innovations of advanced primary and secondary forest products and value chains at the time when the world is entering the era of smart factory and Industry 4.0.

Institutional arrangements, such as incentives, legal regulations, motivational tools (for instance, extension services, tax incentives, education and information) could enhance the service delivery in sustainable forest products innovation and manufacturing as described by Heckett and Aklilu (2009), Doss and Meinzen-Dick (2015), and Rawat (2017). Innovative institutional arrangements aim to forge effective synergies and partnerships among various stakeholders in quadruple innovation helices in order to tap into a wide range of expertise, funds from private investors interested in sustainable forest management, and product manufacturing. Forest products industry parks, similar to the one developed for agro-industries in Ethiopia, are relevant and useful with specialized clusters for biofuel, furniture and construction products. Such cluster approaches are tested and found to be promising in Europe, even in the case of small and medium forest enterprises (Ollonqvist 2011). For this to succeed, the frequent impediments of the forestry sector in Ethiopia, which are loopholes and vagueness of rules and guidelines as well as lack of capacity, should be adequately addressed. Fast tracked decision making, effective coordination, competent skill and knowledge, adequate private sector investment and engagement, need to be availed (MEFCC 2016).

There is a need to increase the capacity of institutions by enhancing advanced technological capacity, expanding the potential innovation cluster of triple and quadruple forest products innovation helices for the sustainable forest products industries. As the first and enabling step, an exhaustive capacity needs assessment is necessary regarding human resources, technology and infrastructure. This should be carried out at national level and sector level, such as biofuel, furniture, wooden construction, in each national administrative region and at task executing units (UNDP 2008). If research institutes and academia form an effective partnership, advanced research and development approaches can help accelerate forest sector transformation (Weiss 2011). This avails state-of-the-art research capability along with pooled advanced laboratory infrastructure, equipment, skilled personnel, strong breeding and tree improvement programmes and nurseries that are indispensable to support the sustainable forest products industry development and innovation in Ethiopia (Suzuki *et al*. 2006, West 2014, MEFCC 2016). The standardised laboratories and workshops (e.g., design and fabrication laboratory infrastructure, creative advanced education programmes at the Ethiopian Technical University; at the Technical, Vocational Education and Training (TVET) colleges; at the Science and Technology Universities) and the facilities of advanced manufacturing technology at innovative industries help to ensure quality forestry education, research, development and innovation of the forest products industry (MOE 2008, Weiss 2011, Gebreeyesus 2016, FDRE 2019). Hence, rapid technological advancement helps to foster development in the forestry sector, enabling competitive sustainable forest products manufacturing that is capable of exporting and capturing new markets. Consequently, a new era of extension and technology transfer will become a reality in Ethiopia in which the stakeholders turn to innovators and the current problems of technology transfer and adoption vanish with time.

Socio-economic development and employment

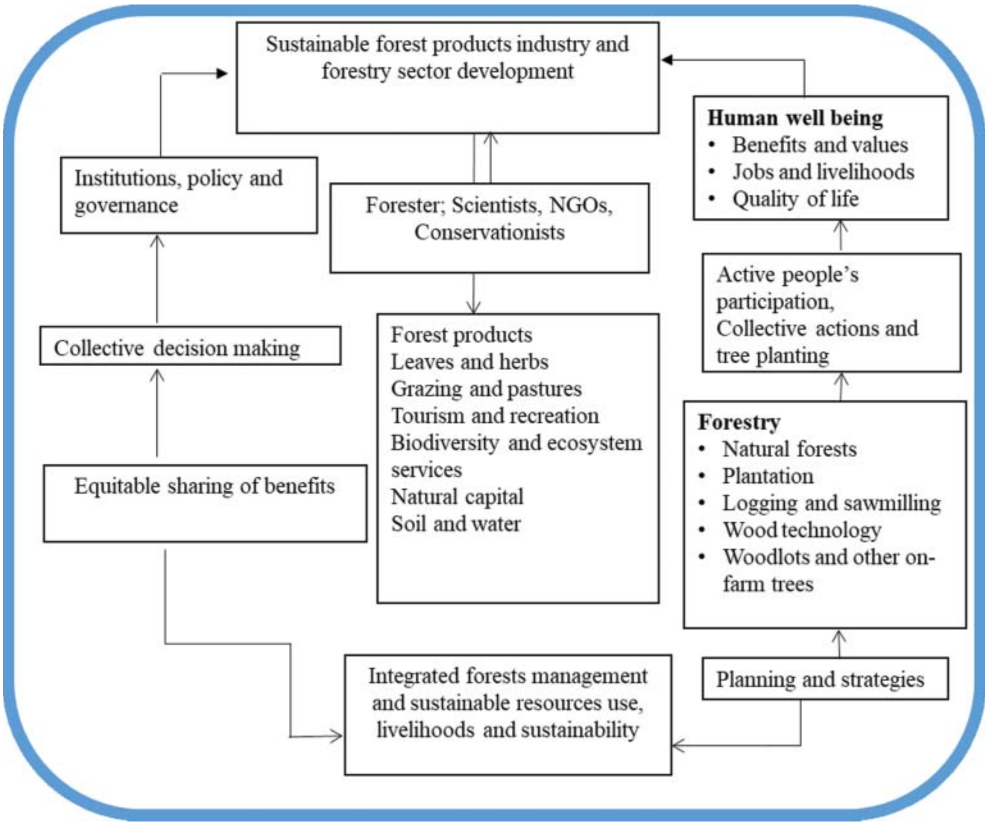
Mamo *et al*. (2007) indicated that forests in Ethiopia make a significant contribution to livelihoods. In particular, they may be responsible for a 60% share of the poor households' income inhabiting forested areas. Generally, the forestry sector and sustainable forest products industry development are vital for the socio-economic development of society and environmental sustainability as they provide job opportunities. Gobeze *et al*. (2009) argued that forest resources are important for the development of Ethiopia. Forest resources directly contribute to the export of non-wood forest products that help to earn foreign currency; household energy; the GDP; rural development and green jobs; enhancement of livelihoods, and provision of environmental services. For instance, Participatory Forest Management (PFM) in Ethiopia has improved the livelihood of beneficiaries and contributed to sustainable forest management (Gobeze *et al*. 2009, Siraj *et al*. 2016, Kedir *et al*. 2018, Wood *et al*. 2019). PFM has also empowered people in order to enhance their livelihood and decision making in forest management (Yemiru *et al*. 2010, Tadesse *et al*. 2017, Gashu and Aminu 2019). About 1.5 M ha of natural forests are currently managed under the PFM scheme in the country (Indufor 2016). Rapid development in the country will put more pressure on forest resources and forest products and as a result the infrastructure development, construction of buildings and houses, and improvement in the living conditions of society are expected to cause more demand for wood products in the near future (Mekonnen and Bluffstone 2008).

Timber plantations (Industrial, non-industrial woodlot and peri-urban plantations) have increased job opportunities. Negede *et al*. (2015), e.g., indicated that the planting of 07 M ha of land in 20–30 years opens avenues for employment and environmental sustainability. On the way forward, there are jobs in silviculture operations (i.e., thinning and tending operations), logging, handling and transport. The sustainable forest products industry, forestry companies, logging firms, sawmills and furniture-based companies will continue helping in creating job opportunities. Nonetheless, the sustainable development of the forest products industry requires balanced improvement and growth both in the economic and social dimensions (Arce 2019, Baumgartner 2019).

WOOD PRODUCTION AND CONSUMPTION

The current figure of around 112M m^3 consumption of wood is expected to reach 158M m^3 by 2033 (MEFCC 2017, UN-FAO 2018). In Ethiopia, limited areas of public plantations

FIGURE 1 *A framework for sustainable forest management and forest products development in Ethiopia thereby contribute to economy and sustainability*



(136,700 ha) and private farm woodlots (778,000 ha) are the current sources of wood supply for the primary and secondary forest products industry (Indufor 2016, MEFCC 2017). The annual consumption of 4.8M m^3 of industrial wood is derived from commercial plantations. Fuelwood has been a prime forest product and as a result, an energy plantation scheme was initiated in 1981, in peri-urban areas of many cities (i.e., Addis Ababa, Nazareth, Debre Berhan, Gondar, Dessie) in order to meet the increasing demand for fuelwood and prevent uncontrolled loss of forests and the resulting forest degradation (Eshetu 2014). A study carried out by Indufor (2016) revealed that existing private woodlots can produce 20M m^3 of wood annually for use as fuelwood, charcoal and construction poles. The annual consumption of timber and industrial wood is reported to be about 7.40M m^3 (UN-FAO 2018). Conversely, the relative consumption of wood was low in modern and non-residential construction, furniture production for urban and rural households, small diameter round wood for utility poles. The respective annual sustained yield for natural and plantation forests has been 28.09 and 14.76M m^3, which has been unable to fulfil the ever-increasing demand for wood. However, new plantations with enhanced productivity and wood flow balance are required to support this in perpetuity. At the species level, a sustained yield production on a per hectare basis was reported higher for *Eucalyptus* followed by conifers (e.g., Cypress and Pines) and *Acacia* species.

The Climate Resilient Green Economy (CRGE) strategy of Ethiopia that was issued in 2011 aimed to increase the extent of rehabilitated degraded areas from 11.7M ha to 22.5M ha. The plan was also to increase the coverage of watershed management from 12.16M ha to 41.35M ha, to increase the contribution of the forest sector to GDP from 4% to 8% and increase the forest cover from 15.5% to 20%. This strategy had a strong emphasis on agriculture and forestry sector development (FDRE 2012, Indufor 2016). The productive aspect of the forest sector development was envisaged to be realized in an industrial cluster approach via establishment of new commercial plantations, improved management of existing public plantations, improved commercial management of natural high forests, improved management of bamboo resources, development and commercialization of NTFPs (MEFCC 2017). The strategy assumed that forestry companies or private sector investment would play a significant role in propagating the opportunities created in sustainable forest products industry development, thereby contributing to the gross domestic productivity (GDP). Conveniently located forest products industry parks (IPs) and an optimal environment should be created for the forestry and sustainable forest products industry development so that foreign direct investment is attracted. Additionally, effective branding and the existence of a differentiated local market is needed for sustainably manufactured forest products in the country rather than relying on imports (Slee 2011). On the other hand, a well-developed and constantly innovating value chain, supply chain and value-added production (like the one implemented for the agricultural sector) is needed for sustainable forest products industry development and innovation.

The constantly improving value chains are important for the competitive supply of forest products (Indufor 2016). For instance, the furniture industry is vital and consumes more wood panels and sawnwood. Against this backdrop, such products should compete with imported ones which are being efficiently manufactured with 15-fold labour productivity and half of the raw material cost (Dinh *et al*. 2012). To mitigate this problem, the value chain should be developed in such a way that the best research and development support is rendered for logging, sawmilling, sustainable forest management and efficient forest products enterprises.

Ten-year time series data is presented in Table 4 (Export-production) to show the volume of major forest products manufactured in Ethiopia in which a general steady increase is shown. Several new plywood, particleboard, MDF and sawnwood factories have started operation or are in the process of commissioning and this is reflected in the increased volume of production, particularly in the last five years.

Industrial plantations, private and community woodlots and even natural forests are the source of wood supply for the forest products industry in Ethiopia. Industrial plantations supply about 3.2M m^3 of wood annually in order to meet the respective demand, while private and community woodlots, woodlands and natural forests are utilized to meet the annual demand of about 110M m^3 of wood that is used for fuelwood and charcoal, construction wood, utility poles and posts (Indufor 2016). Currently, the country is heavily reliant on imported forest products (e.g., sawn lumber, panels, utility poles) and raw materials (e.g., pulp, paper), but better developed and supported forestry and sustainable forest products industries could save millions of dollars. Although, the tax-free import of wood products is aimed at reducing forest degradation, the purpose has not been served. However, the same purpose can be served by increasing wood production locally (Reda and Beshah 2018). Additionally, the species, biome and region-wide density, volume and basal area data which are results of the recent NFI along with the work of Bekele-Tesemma (2007) in combination with the on-going research programmes of the Ethiopian Environment and Forest Research Institute of Ethiopia, can be used for better development of the forest resources base. Furthermore, in this time of weakened forest health and increased vulnerability due to climate change, the best silvicultural practices and tending operations, as well as protection, must be adopted for sustainable forest industry development (Suzuki 2006, West 2014).

The status and development of a sustainable and competitive forest products industry

The status and development of the Ethiopian forest products industry is assessed in this section by focusing on the resources base, manufacturing and marketing of the following major forest products: fuelwood and charcoal, industrial roundwood and poles, sawmills and lumber production, wood composites, pulp and paper, wood furniture and joinery products.

Fuelwood and charcoal

Fuelwood has been the primary source of energy in rural areas of Ethiopia (Mulugetta 1999, Gabisa and Gheewala 2018, Sime *et al*. 2020). Poverty and lack of energy resources have led to chronic degradation of forests due to excessive harvesting of fuelwood from nearby forests (Bekele *et al*. 2016). Fuelwood is the most widely used form of energy for cooking and space heating in developing countries (Rawat *et al*. 2009). Ethiopia, as a developing country, has a high dependency on biomass energy, including the use of cow dung for fuel (Geissler 2013). According to the Forest Sector Review of MEFCC (2016), about 120.4M m^3 of roundwood equivalent (which is composed of 115.024 and 5.408M m^3 of fuelwood and charcoal, respectively) of wood is harvested annually from forests for fuel. The demand for furniture, timber, construction and other forest products manufacturing has been putting an additional burden on biomass systems (Geissler 2013). Charcoal production, distribution and consumption need to be brought under some strategic protocols and regulations. Reports indicated that the collection of fuelwood and production of charcoal are the main causes of forest degradation in Ethiopia (Kilawe and Habimana 2016, MEFCC 2016, Indufor 2016). The recent estimate of annual fuelwood consumption in Ethiopia was about 133M m^3 and 90% of the cooking energy supply is obtained from woody biomass. According to Moges *et al*. (2010), wood accounts for 99.9% of rural energy supply. Moreover, hotels and universities in Ethiopia prefer to use fuelwood because it is a cheaper source of energy. As a result, fuelwood has become an important forest product in Ethiopia (Assefa and Bork 2013, Indufor 2016).

To reduce pressure on forests and improve quality of life, quadruple stacking of energy sources (such as LPG, biogas, photovoltaic devices, solar cookers, and energy efficient technologies) must be recognized and distributed to society (Geissler 2013). Afforestation, as well as the use of marginal farmland and bare forest land for energy woodlots, appears to be required to increase overall wood production, particularly fuelwood production. Currently, charcoal production and marketing support the livelihoods of poor rural dwellers. The efficient charcoal production and sustainable harvesting of fuelwood will continue to create new jobs in rural areas and contribute to environmental sustainability (UNEP 2019).

It is widely known that charcoal production is an important source of income and employment opportunities for millions of people in Ethiopia. As indicated by Melaku *et al.* (2016), the charcoal value chain is highly complex, but well organised and barely visible. Its operation involves a wide range of actors through multiple and versatile production-supply channels. The revenue generated is large and the financial circulation is intricate and heavily reliant on informal systems. The production is entirely carried out using inefficient traditional technologies (earth-mound and earth-pit, which are only about 10% efficient). The most frequently used tree species for charcoaling are native hardwoods, mainly *Acacia*, *Terminalia* and *Combretum spp.*, and are mostly sourced from illegal open-access state and community/kebele woodlands. Despite the significant economic and employment benefits of the charcoal industry to the millions

TABLE 4 *Ten-year time-series production, import and export data and trends of evolution for major forest products in Ethiopia based on data obtained from UN-FAO (2015), UN-FAO (2020), CSA (2015) and CSA (2018)*

Forest products	Unit	Annual Production in Thousands Unit									
		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Sawnwood production*	m^3	9,162	24,521	97,379	167,826	155,556	214,260	293,560	916,867	1,390,894	775,530
Plywood production*	m^3	930	133	5,303	5,817	4,907	5,350	5,384	88,521	765,573	2,181,101
Particleboard production*	m^3	7,266	129,630	556,704	582,660	889,154	899,543	487,303	91,018	232,484	4,492
Paper production*	Tons	7,565	11,058	10,147	12,490	10,699	117,544	118,793	11,200	21,555	42,692
Boxing paper production*	Tons	11,501	11,216	10,250	10,241	10,176	15381	14,462	67,924	71,447	83,133
Round wood Production''	m^3	102,805	104,209	105,544	106,901	108,281	109,683	111,109	112,324	113,557	114,810
Round wood Import''	m^3	5	1	5	2	7	15	5	4	2	2
Round wood export''	m^3						3	3	3	0	0
Industrial round wood production''	m^3	2,935	2,935	2,935	2,935	2,935	2,935	2,935	2,935	2,935	2,935
Industrial round wood Import''	m^3	5	1	5	2	7	15	5	3	2	2
Fuel wood production''	m^3	99,870	101,274	102,609	103,966	105,346	106,748	108,174	109,389	110,622	111,875
Wood fuel import''	m^3								1		
Wood fuel export''	m^3						3	3	3		
Charcoal production''	Tons	3,644	3,734	3,827	3,921	4,018	4,118	4,220	4,317	4,416	4,518

*Data obtained from CSA of Ethiopia (2015, 2018)
''Data obtained from UN-FAO (2015, 2020)

of Ethiopians, it has been inflicting a heavy impact on the environment and conserved dryland forest resources owing to the unregulated operation of the charcoal sub-sector (UNEP 2019). There is an urgent need to regulate charcoal production and innovate the entire value chain. Efficient charcoal kilns which are appropriate for household as well as plantation level production should be developed and promoted. Traditional charcoal making has a conversion rate of about 10%, thus efficiency improvement measures can significantly reduce the wood biomass feedstock required to make the same amount of charcoal. Such measures at the same time will decrease greenhouse gases (GHGs) and toxic gas emissions significantly (Tekleyohannes 2019, Tekleyohannes and Worku 2019). Innovative product tracing and certification tools such as blockchain technology should be immediately introduced and implemented in order to ensure the sustainable production, socially responsible marketing and consumption of charcoal (UNEP 2019).

Industrial roundwood and poles

Sustainable forest sector development secures a reliable supply of industrial roundwood for forest products manufacturing (e.g., primary and secondary forest products) (Jürgensen *et al*. 2014). In Ethiopia, industrial roundwood production is projected to be about 1.5M m^3 and 1.6M m^3, for the year 2025 and 2030, respectively, which is one of the lowest in the world (Bekele 2011). Most of the roundwood used for utility poles comes from industrial plantations in the country, while the construction sector gets most of the wood supply from private woodlots. At the species level, the highest roundwood production is obtained from *Eucalyptus* species followed by *Cupressus lusitanica* and *Pinus* species. Primarily, *Eucalyptus* species are used for poles and posts in Ethiopia, while logs of the same species are also exported to neighbouring countries, which is considered to be the second most exported commodity in the Ethiopian forest products sector (Alem 2015). Ethiopia also imports roundwood and manufactured products to meet domestic demands. Jürgensen *et al*. (2014) pointed out that global industrial roundwood supply will increase from 1.8B m^3 in 2000 to 2.3B m^3 by the year 2040. Similarly, industrial roundwood and poles demand in Ethiopia has been increasing as a result of large-scale developments in the housing and infrastructure sectors. The largest roundwood demand comes from the construction sector. The second Growth and Transformation Programmes (GTP-II) of the country, for instance, was scheduled to build one hundred and fifty thousand (150,000) residential units annually. Furthermore, more than 70% to 90%, and 90%, of housing in Ethiopia's urban and rural areas, respectively, are deemed substandard and require drastic and immediate improvement. The cumulative effect of all this is that there is a high demand for construction materials, mainly for roundwood (UN-Habitat 2008, Weldesilassie *et al*. 2016). Ninety-two percent of the wood used in construction is of *Eucalyptus* species in the form of roundwood (Mekonen *et al*. 2007, Zerga and Berta 2016, Dessie *et al*. 2019).

About 81% (80 million) of the population of Ethiopia is rural. Based on the CSA and WB (2013) survey, the average number of households that needed immediate improvement in the country was about 1.5M. If all these households are assumed to be provided with significant improvement in their living conditions, and with a change of respective housing units into one with a corrugated iron-roof at the end of successful GTP-II, then according to Duguma and Hager (2010), there is already a need for an increased annual roundwood supply of 1.4M m^3, in addition to the recurrent annual demand of about 2.9M m^3 (UN-FAO 2016). This demand should be met by increased planting of more *Eucalyptus* trees as well as through efficient utilization technologies. The other demand for roundwood comes from the country's National Electrification Programmes (NEP) which will increase the demand for electric transmission and distribution poles by almost 150%, when the national electricity access will be increased from its current status of about 38% to 100% by the year 2030 (FDRE 2019). The remaining industrial roundwood comes from the growing number of wood composites industries in the country.

This will exert significant pressure on the country's limited industrial roundwood resources. The country's current industrial plantations are over-aged and poorly managed and maintained on a silvicultural level: failing to meet the current and increasing demand for roundwood. Hence, repurposed management of existing and over-aged industrial plantations, accelerated establishment of new plantations and tree plantings by farmers are needed to meet the exponentially growing demand for roundwood and poles. Indeed, Jürgensen *et al*. (2014) projected that 44 and 46% of the global roundwood demand in 2020 and 2040, respectively, needs to be met by industrial plantations.

Sawmills and lumber production

Sawmills in Ethiopia are typically characterized by low utilization capacity and outdated equipment, resulting in low recovery rates and the generation of a large amount of waste (Abebe and Holm 2003). Most of the mills are old and designed to convert large sawlogs of indigenous species (Alemseged 2015). Typical technologies used in the Ethiopian sawmills are wide bandsaws, narrowband table saws that are used both for primary breakdown and as resaws, and circular saw headrigs (Reda and Beshah 2018). As a result, sawmills constantly struggle to maximize the yield and the rate of lumber recovery. Maximizing the volume recovery of lumber from logs is one of the most common ways of improving the conversion efficiency and competitiveness in lumber production. However, the quantity of lumber produced from a certain volume of logs is affected by several factors related to characteristics of logs (species, log diameter, length, defects), technology, sawing pattern, lumber dimensions, quality of sawmills, training and experience of machine operators. The lumber recovery factors vary with log diameter and taper (Missanjo and Magodi 2015). Such factors have a direct and significant impact on the lumber recovery. Multipurpose and rational utilization of timber is now enabling almost 100% recovery of lumber and wood chips. It is here that significant innovation is needed. CT (Computed Tomography) and 3D scanning technologies enable defects to be seen which were previously hidden, and optimal breakdown patterns are automatically deduced (Lin and Wang 2013, Fredriksson 2014, Rias *et al*. 2017, Wang *et al*. 2018). In the Ethiopian context, the advanced systems for logging and sawmill industries are needed to maximize the grade yield and the rate of lumber recovery.

The majority of sawmills in Ethiopia are installed near forest resources, yet sawnwood market centers such as Addis Ababa are located a long distance away. The long-distance supply chain has been adding operational costs. To increase efficiency and effectiveness, old sawmills must be replaced with modern ones. Almost all mills cut lumber through-and-through to reduce log rotation and handling on carriages and feeding mechanisms, however, each flitch sawn from the log using such methods necessitates more edging (Anderson and Westerlund 2014). Therefore, low-cost lumber recovery optimization and simulation technologies need to be introduced and promoted in sawmills in order to maximize value (Mwamakimbullah 2008, Trybus and Wietecha 2016).

A significant amount of lumber is still pit-sawn by hand using axes and two-man saws, with a very low rate of lumber recovery. Particularly, this is true for hardwood lumber species that are considered as overexploited and restricted for utilization. On the other hand, the use of chainsaws with appropriate milling fixtures for lumber production can boost the recovery rate to as high as 60% (Wit and van Dam 2010). Small scale and appropriate dry kiln technologies need to be promoted for the control of moisture of the lumber and quality improvement. Dehumidification and solar kilns technology are helpful for most of small-scale sawmill operations.

Our observations indicate that lumber grading is being done solely on the basis of dimension (thickness and length) and species. Sawmills need to introduce appropriate lumber grading and classification standards so that transactions are done with ease for locally manufactured lumber. The sawmill industry is important for this sub-sector because it has a share of about 29% in the import of primary forest products, based on data obtained from the Ethiopian Ministry of Revenue.

Wood composites, pulp and paper

Wood composites are engineered wood products that are used both for furniture and construction. They consist of wooden materials bonded together, usually with adhesives, and include particleboard, plywood, fibreboards, oriented strand board (OSB), batten board, cross-laminated timber (CLT) (Thoemen *et al*. 2010, Cai 2011). Particleboard, fibreboard and plywood are the composites manufactured locally in Ethiopia mainly from *Eucalyptus* species (Dessalegn and Tadesse 2010, Kelemework 2012). There were only three particleboard factories a decade ago, along with one plywood and one fiberboard factory. The number of composite board factories has recently increased significantly and now they are more than 20 with several more in the planning or construction phases. CSA data indicate that about 95% of locally manufactured composite board used to be particleboard while plywood takes the remaining share, though the share of locally manufactured plywood has been increasing with the start of operation of newly installed mills (CSA 2015, 2016, 2017a, 2017b, 2018, 2019). The import data from the Ministry of Revenue shows a different structure with plywood taking about 45% of the share, followed by MDF (24%), particleboard (10%), laminated wood (18%), and OSB about 3%.

Ethiopia relies completely on imported pulp. According to the Ministry of Revenue, imports of pulp and paper account for more than 63% of the structure of imported primary wood products, with pulp and paper accounting for about 6% and 57%, respectively. Economic development will continue to induce increased demand for wood panels, particleboard, MDF, pulp and paper (Indufor 2016). The report suggests that demand for wood products will increase exponentially throughout the years to 2040. In contrast, existing forest plantations will be reduced by 50–55% due to old-age, poor management regime and low productivity. Hence, synergy and a link are crucial for woodlot owners and tree growing associations with industries to strengthen the upstream forest industry (Indufor 2016). The synergy creates opportunities for tree growing farmers to produce more biomass from farmland. Most importantly, a vertically integrated Commercial Forestry Investment Plan (CFIP) is vital for sustainable forest products manufacturing and forestry sector development, supporting rural livelihoods, and creating jobs for a carbon-neutral society and a climate change resilient green economy (CRGE).

Wood Furniture and Joinery Products

The Forest Sector Review (FSR) (2015) predicts that there will be a four-fold increase in the demand for furniture by the year 2033. Similarly, CSA data show exponential growth trends in the demand for wood furniture, with the value-added and profit margins following the same trend in micro-, small-, large- and medium scale furniture manufacturing (CSA 2015, 2016, 2017a, 2017b, 2018, 2019). The same CSA surveys indicate that the sector is dominated by small and micro-enterprises. According to the Ethiopian Ministry of Revenue, the value of imported furniture such as household, office, kitchen and restaurant furniture, generally been displaying a similar trend. The majority of imported furniture is of household type (43%) followed by the kitchen (35%), office (22%), and restaurant type furniture which has a share of below 1%. This is an outcome of urban housing construction development and urban-dwelling improvement.

According to the natural resource-based view (NRBV), developing countries such as Ethiopia have a comparative advantage in the manufacture and marketing of wood furniture due to their labour-intensive nature combined with natural resource endowment and lower carbon emissions (Lähtinen 2007, Tanaka and Hailu 2015, Koch 2020). However, empirical observations show contrary findings to this conventional wisdom. For instance, medium-scale furniture manufacturing plants are almost all shut down in the city of Bahir Dar while imported furniture outlets are expanding in the same city (Cherkos *et al*. 2018). The situation in Addis Ababa, the capital city, is similar and manufacturers here, too, are not able to understand why imported furniture is cheaper, more attractive and of better quality than their domestic products. There is a need to develop the advanced factor conditions in terms of consumers' satisfaction needs assessment, product development and innovation. Current graduate students of the Ethiopian Technical University (ETU) are investigating the attractiveness, performance, reversing and indifference attributes of wood furniture as perceived by users employing the method introduced by Kano *et al*. (1984) and that was recently improved by Madzík (2018) in order to decipher the puzzle. Indeed, the Wood Technology B.Sc. and M.Sc. programmes at the ETU will need to be strongly supported so that they can contribute to the provision of advanced skills and knowledge that is critically needed to innovate the wood furniture industry. There are completed and ongoing graduate students' research activities on the economic and environmental dimensions of the furniture industry (Getaneh 2014, Tekle 2014, Teshome 2015, Wubishet 2015). The furniture industry cluster should be supported so that it is vertically integrated and developed with related industries.

CONCLUSION

This review has demonstrated that Ethiopian forests have the capacity to serve both productive and ecosystem functions so that they can be used as an effective tool in achieving the country's CRGE as well as the Global Goals, to which Ethiopia is committed. The Ethiopian forest products industry needs vertical integration, which will not only enable easy optimization of the three pillars of sustainability (economy, society and environment), but can also efficiently support both the CRGE and the achievement of sustainability goals. This is the first study to look at the Ethiopian forest products industry development from its resource base to the consumption of intermediate and final products. As a result, it can be used as a comprehensive and vertically integrated resource for decision-making and policy support in the field of sustainable forest product innovation.

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