The future of planted forests

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SUMMARY

Although planted forests have produced forest products for centuries, the past 4-5 decades has seen an increase in diversity of species, areas planted, growth rates, harvest yields, forest products and the acknowledgement of a wide range of ecosystem services. This paper highlights the potential role of planted forests towards the mid-21st Century through changing conditions including climate, indigenous forest resources, land availability, socio economic and environmental conditions, innovative forest and forest industries technologies, market demands for sustainability and legality and new innovations in green growth economies. Lessons learned from the past will assist in determining the issues, opportunities, and challenges facing the future of planted forests.

Keywords: planted, sustainability, circular bioeconomy, wood, ecosystem services

Futur des forêts de plantation

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Bien que les forêts de plantation aient fourni des produits forestiers depuis des siècles, les 4-5 dernières décennies ont connu une augmentation de la diversité des espèces, des zones plantées, des taux de croissance, des quantités de récolte et des produits forestiers, ainsi qu'une reconnaissance d'un large éventail de services d'écosystèmes. Ce papier souligne le rôle potentiel des forêts de plantation en se projetant vers le milieu du XXième siècle au travers de conditions changeantes incluant le climat, les ressources des forêts indigènes, la disponibilité des terrains, les conditions socio-économiques et environnementales, les technologies forestières et d'industries forestières innovantes, les demandes du marché pour la durabilité et la légalité, et de nouvelles innovations dans les économies de croissance vertes. Les leçons tirées du passé vont aider à déterminer les questions, les opportunités et les défis auxquels fait face le futur des forêts de plantation.

El futuro de los bosques plantados

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Aunque los bosques plantados han venido proporcionando productos forestales durante siglos, en las últimas cuatro o cinco décadas se ha observado un aumento de la diversidad de especies, de la superficie plantada, de las tasas de crecimiento, de los volúmenes de aprovechamiento, de los productos forestales y del reconocimiento de una amplia gama de servicios ecosistémicos. En este artículo se pone de relieve el papel que pueden desempeñar los bosques plantados hacia mediados del siglo XXI en unas condiciones cambiantes, como el clima, los recursos forestales autóctonos, la disponibilidad de tierras, las condiciones socioeconómicas y ambientales, las tecnologías innovadoras en materia de bosques e industrias forestales, las demandas del mercado en materia de sostenibilidad y legalidad y las innovaciones emergentes de las economías ecológicas de crecimiento verde. Las lecciones aprendidas en el pasado ayudarán a determinar las problemáticas, las oportunidades y los desafíos a los que se enfrenta el futuro de los bosques plantados.

INTRODUCTION

This paper highlights that planted forests and trees were cultivated by different cultures around the globe for millennia but the role of planted forests in sustainable management of forests throughout Europe gathered momentum from the 17th Century and expanded globally during the European colonial era. The early-mid 20th Century saw increasing collaboration between Government agencies and emerging international agencies and the processes demonstrated and guided the policy, legal, regulatory, institutional reforms, the technical and operational actions required for the transitions to reduce dependence on indigenous forest resources and increase the role of planted forests. In the latter half of the 20th Century, as the role of private sector investment in planted forests expanded, social and environmental safeguard challenges emerged that required more participatory and partnership approaches, including emergence of smallholder and outgrower schemes. This paper draws upon the outputs of international planted forests events in guiding trends and likely outcomes as reflected in the results of the Global Thematic Study on Planted Forests (FAO 2005) and the various Global Outlook Studies over the past two decades. The paper highlights key influences, lessons learned and challenges and opportunities that are guiding the increasing role of planted forests in the provision of forest products and ecosystem services in the future.

PAST PLANTED FORESTS CONTEXT

Early plantings

Records show Olive trees (*Olea europaea*) were planted in Greece as early as 3000–4000 BC; tamarisk (*Tamarisk aphylla*) in Israel about 2000 BC; myrrh (*Commiphora myrrha*) in Egypt and frankincense (*Boswellia* spp.) in Southern Arabia about 400 BC. The Chinese grew ornamental and fruit trees as long ago as 2000 BC and a forest service was established to preserve indigenous forests, reforest denuded lands and produce wood from 1100–256 BC (Shon-Ching Lee *et al.* 1948).

Fledgling planted forests in Europe and their colonies

Until the early 19th Century, planting in Europe was primarily reforestation of former forest areas with indigenous species. However, increasingly from that time afforestation of bare land was undertaken with pines (*Pinus pinaster* and *Pinus sylvestris*) and spruce (*Picea abies*) or conversion of broadleaved forests to conifer. Increasingly, introduced species such as *Picea abies*, *Picea sitchensis*, *Pinus nigra*, *Pinus contorta*, *Pseudotsuga menziesii* and *Larix kaempheri* were planted widely across the UK and Europe. Other introduced species planted widely included *Eucalyptus globulus* in the Mediterranean region and *Pinus radiata* in northern Spain, Australia, Chile, New Zealand and South Africa. Planted forests spread to countries influenced by European colonizers in Asia, Africa and Latin America as a substitute wood resource (Evans 2009).

First half of the 20th Century: Government planting on State land

Government plantings on State land expanded during the first half of the 20th Century in all regions. Examples include: Australia (*Pinus radiata*, *P. elliottii*, *P. pinaster*, *Araucaria cunninghamii*), Brazil (*Eucalyptus* spp.), India (*Tectona grandis* and *Eucalyptus* spp.), New Zealand (*Pinus radiata and other Pinus* spp.), USA (*Pinus elliottii* and *P. taeda*), South Africa (*Pinus patula*, *P. elliottii*, *Acacia mearnsii* and some *Eucalyptus* spp.) and Kenya (*Pinus*, *Cupressus* and *Eucalyptus* spp.).

Increasing internationalism

After the Second World War, the establishment of the Food and Agriculture Organization of the United Nations (FAO) provided funds, development aid and technical support to Governments for planted forest investment demonstrations around the world. The increasing independence of countries and the declining influence of colonial powers altered economic and development policies to meet peoples' aspirations. Planted forest areas increased substantially as part of the development process in many developing countries. At this time, the Centre Technique Forestier Tropical; the Institute of Tropical Forestry; and Centro Agronomico Tropical de Investigacion y Esenanza (CATIE); and many universities and forestry colleges were established and added to the momentum in planted forest investments and increasing knowledge of silviculture, harvesting and utilization of wood from planted forests.

Increasing internationalism with respect to planted forests was led by the Fourth World Forestry Congress in India in 1954 which recommended that an international commission be set up on the use of introduced species for planting in the tropics, under FAO. The Seventh British Commonwealth Forestry Conference hosted in Australia and New Zealand in 1957 requested that a book be published to synthesize the experiences with planting of exotic species in commonwealth countries (Streets 1962). In 1957 a Sub-committee on Planting of Exotic (Eucalyptus and Pinus spp.) was established under the Asia Pacific Forestry Commission of FAO. Notable planted forest publications by FAO in the 1950's included Eucalypts for Planting (1955) and Poplars in Forestry and Land use (1958). In 1962 The Eucalyptus Clearing House (now the Australian Tree Seed Centre at CSIRO) was established in Australia to provide registered seeds and technical information for research and commercial *Eucalyptus* plantation expansion around the world (Palmberg-Lerche 2002).

Planted forests gain traction

FAO, International Union of Forest Research Organizations (IUFRO) and Australia hosted the World Symposium on

Man-made Forests and their Industrial Importance in Canberra in 1967 that resolved to increase use of new technologies, pursue genetic quality and diversity, expand growth and yield research and development, intensify silvicultural management inputs and invest in new wood industries to cater for the expanding role that planted forests would play in the future production of wood, fibre and woodfuel and/or environmental protection around the world (FAO 1967).

Many of the planted forests established in the 1950's and 1960's accelerated in the 1970's, new research and development was undertaken in improved germplasm, nursery practices, silviculture, harvesting, utilization and forest protection. Planting expanded rapidly and planted forests became enabled as priority actions in forest policies and strategies and incentives were given to encourage private sector and smallholder investment in planted forests production and utilization (IFF 1999). During this period plantings in Oceania, Europe and African countries expanded rapidly and China, India and Brazil embarked on ambitious planting programmes. This coincided with an increasing role of agroforestry and expansion in technical support, extension services and seedlings to smallholders and farmers for planting in woodlots, agroforestry plots, home gardens, shelter belts and along roadsides (Evans 2009). The International Council for Research in Agroforestry (ICRAF) was then established in 1978 to promote agroforestry research in developing countries (ICRAF 2020).

Emergence of social, environmental and economic challenges

Although the global planted forest resource expanded rapidly, in some developing countries a lack of Government resources required to undertake silvicultural management on planted forests on primarily State land caused failures or even abandonment, with examples from Africa including Cameroon, Gabon, Liberia and Zaire (Evans 2009). In other instances, where planted forest received little management the untended, unpruned and unthinned crops were retained well beyond their optimal harvest rotation. This was due to a lack of available resources and a lack of knowledge of the end use properties and potential, wood processing facilities and market acceptance of planted forest species. In other instances, the lack of engagement or partnership with local communities and indigenous peoples led to disrespect of the planted forest investments with displaced or disadvantaged peoples using fire as a protest and encroachment or illicit harvest to access land and provide income for poverty reduction and to meet livelihoods needs (Lexterra 2016, Malkamaki *et al*. 2018).

Planted forest investments in Malawi, Zambia, Tanzania, Kenya and Madagascar were sometimes suboptimal due to competition and uncertainty between agricultural and forestry land use exacerbated by the complexities between Government ownership and traditional/customary land ownership and land use; financial analyses inadequately reflected alternative land uses, the uncertainty of enduse wood processing and placing new forest products from planted forests on the market; and the low stumpage rates gave the Government low rates of return (World Bank 1977).

Initial private sector investment in planted forests

From the 1990's Government forest policies and international funding institutions encouraged private sector investment in planted forests in response to the growing world demand for wood, fibre and woodfuel. Private sector industrial planted forest investments also faced social and environmental issues that included conflicts in land tenure and traditional land use and competition with agriculture, displacement of people and in some instances, the wrong species planted by the wrong people, in the wrong places for the wrong reasons. This initially pitted private companies against local communities and their traditional access to natural resources and resulted in a loss of confidence by key stakeholders (Malkamaki *et al*. 2018). Experiences in Indonesia, Thailand, Vietnam and Malaysia in south east Asia have demonstrated that the expansion of planted forests by the private sector needed to incorporate participatory planning to take into account local livelihood practices, traditional resource tenure systems and settlement histories as they influence how communities respond to and participate in planted forest investments (Barney 2004). This approach required a rethinking of the roles and mechanisms of partnerships between the Government, the private sector and smallholders.

There are many different variations to models, but companies can provide smallholders with improved genetic stock seedlings, technical support, materials and access to markets Byron 2001, Carle 2007). The smallholders have the land, labour and generally give a commitment to deliver a planted forest crop to the company on maturity. The Government needs to have a clear and consistent enabling policy and implementation regulation. The companies need to bring investment and proven social and environmental responsibilities, and the willing smallholders need to be prepared to honour partnership agreements. In Africa, the Uganda Sawlog Production scheme successfully supported planting of more than 10,000ha of smallholder plantings; and in the Southern highlands of Tanzania, smallholders own about 139,000 ha of planted forests, the Government 36,000 ha and private companies, 20,000 ha (Jacovelli 2014; Dewees pers.com.).

Accelerated expansion of planted forests in the last half of the 20th Century

From the 1980's planted forest resources expanded rapidly in Chile, India, USA (Prestemon and Abt 2002), China (Zhang and Song 2006), Canada, Brazil and Indonesia (FAO 2010a). With population growth, the increased demand for wood, fibre and woodfuel could not continue to be met from natural forests and the restoration of degraded lands became increasingly important (Evans 2009). During this period there was a focus on intensification of management; improved germplasm and expansion in the application of biotechnology for vegetative propagation of clonal seedlings; more refined site-species matching; tailoring of nutrient applications based

on soil and foliar analyses; increased mechanization of site preparation, tending, and silviculture; increased recognition of the need for effective forest protection to reduce vulnerability to fire, insects, diseases and other pests to maintain and increase planted forest productivity and health in successive rotations; and the emergence of growth and harvest yield modelling based upon long term monitoring of permanent sample plots in planted forests with the purpose of production (IFF 1999).

During this period planted forest development for protective purposes accelerated for the restoration of degraded lands. In China planting of poplars and other species was adopted to combat desertification in the Three North Shelterbelt Programme and regreening of the watersheds, embankments and the flood plains of the Yangtze, Huai and Yellow Rivers in Central China (Carle and Ma 2005). Protective plantings of poplars and willows in the Parana delta were for flood control of Buenos Aires (Kollert, Carle and Rosengren 2014); watershed protection in highly erodible pumice soil landscapes (Rhodes 2001) and coastal sand dune restoration (Berg 2006), both in New Zealand.

TRENDS IN PLANTED FORESTS

Scope and concept

It was recognized by the expert consultative group guiding the Global Forest Resources Assessment 2005 on behalf of countries that the plantation forest definition from former assessments was inadequate in accounting for the planting of indigenous species in seminatural forests prevalent in European countries and Canada. FAO coordinated the dialogue that agreed on the planted forests scope, concept and definition as reflected in Figure 1 which has been used as the basis for the Global Planted Forests Thematic Study, 2005 and subsequent Global Forest Resources Assessments (FAO 2006a, 2008, 2010a and 2015).

According to the Global Planted Forests Thematic Study associated with the Global Forest Resources Assessment 2005, about half of seminatural forests were regenerated by assisted natural regeneration and half by planting of indigenous or native species. About 76 percent of the global planted forests area was for productive purposes and 24 percent for protective purposes (FAO 2006a). The ratio of productive/protective purposes by area percentage varied considerably between regions as displayed in Figure 2, with North, Central and South America and Oceania in the range 96/4; Africa and Europe, 80/20; and Asia, 65/35 with a strong influence of China combating desertification, flooding and flood plain restoration (FAO 2006a).

Planted forest area 1990–2015

Planted forest trend data from the FAO coordinated Global Forest Resources Assessment 2015 included past data for each reporting country by region for 1990, 2000, 2005, 2010 and 2015. These are summarized in Table 1 and displayed in Figure 3 giving regional and global totals.

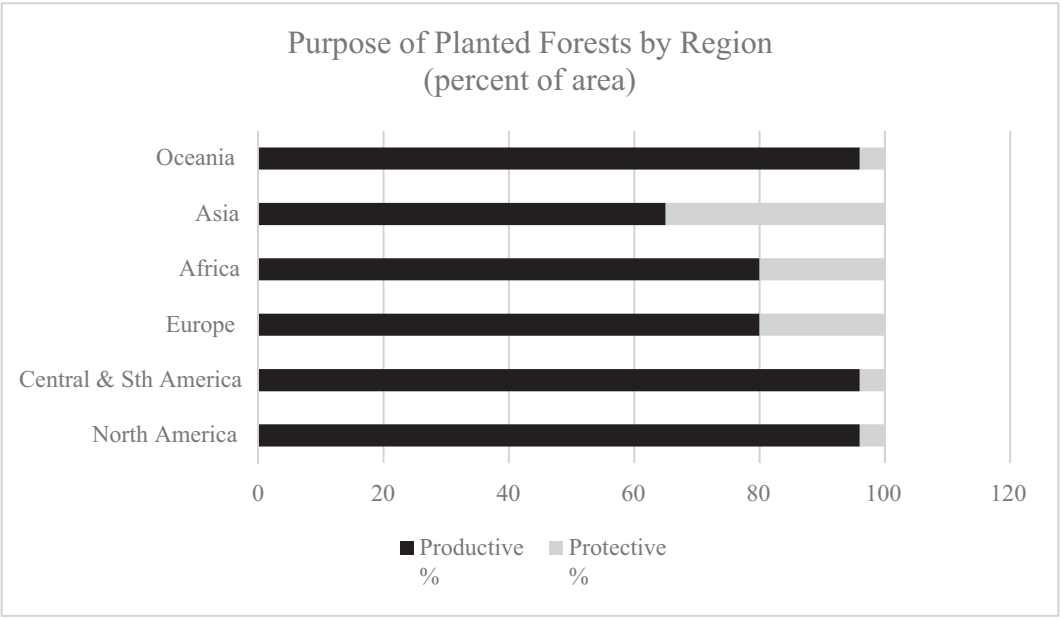
According to Global Forest Resources Assessment country reporting, from 1990–2015 the planted forest area, in millions of hectares, increased modestly in Africa (1.6 percent per year) and Europe (1.8 percent per year) which showed some signs of slowing in the latest 2015 reports. In comparison, the planted forest area increased more strongly in Oceania (3.4 percent per year), Central and South America and the Caribbean (3.4 percent per year), North America (3.5 percent per year) and Asia (3.1 percent per year). The global planted forest area from 1990–2015 expanded from 176.1 million hectares to 293.4 million hectares (2.7 percent per year); from 1990–2000 expanded at 2.4 percent per year; from 2000–2010 expanded at 2.7 percent per year and from 2010–2015 expanded at 1.2 percent per year (FAO 2010a, 2015). Changes in definitions and country interpretations and reporting make it difficult to compare data and draw conclusions on

FIGURE 1 *Scope and concept of planted forests*

Continuum of Forest Characteristics						**Non-forest**
Primary forest	**Modified natural forest**	**Semi-natural forest**		**Plantation forest**		**Trees outside forests**
		Assisted natural regeneration	**Planted**	**Productive**	**Protective**	
Forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed	Forest of naturally regenerated native species where there are clearly visible indications of human activities	Silvicultural practices for intensive management (weeding, fertilizing, thinning, selective logging)	Forest of native species, established through planting, seeding or coppice of planted trees	Forest of introduced species and in some cases native species, established through planting or seeding mainly for production of wood or non-wood goods	Forest of native or introduced species, established through planting or seeding mainly for provision of services	Stands smaller than 0.5 ha; trees in agricultural land (agroforestry home gardens, orchards); trees in urban environs and scattered along roads and in landscapes
			← **PLANTED FORESTS** →			

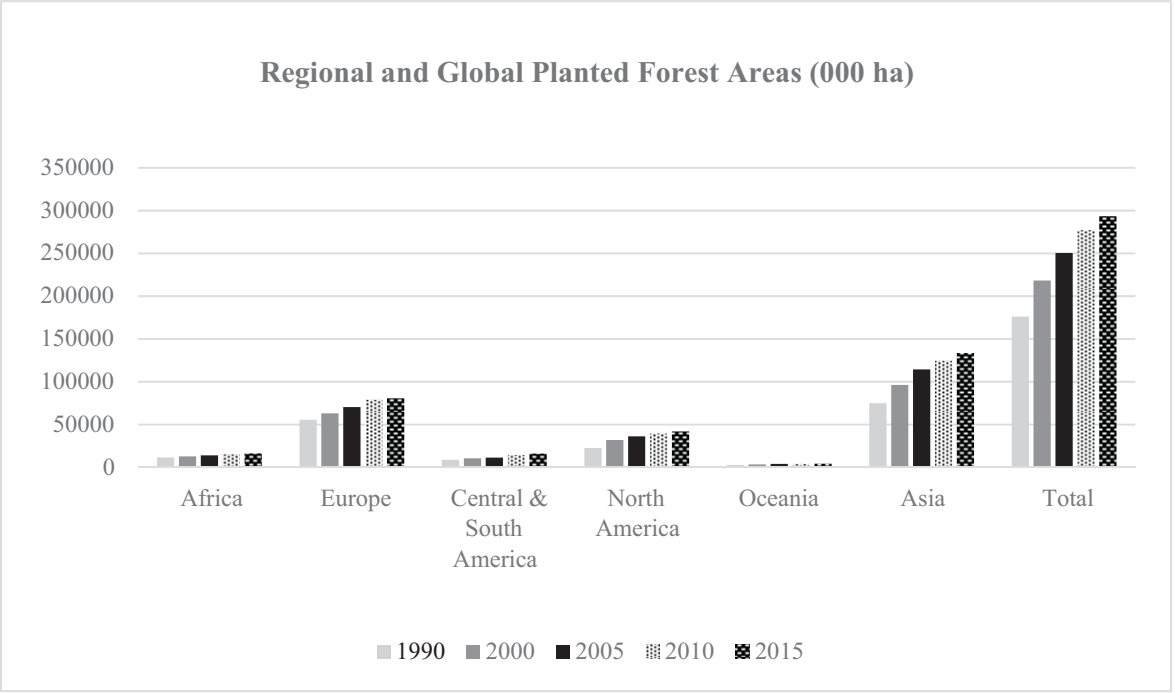
Source: FAO, 2005

FIGURE 2 *Purpose of planted forests by region*



Source: Planted Forest Thematic Study, FAO, 2006a

FIGURE 3 *Comparative distribution of regional and global planted forest area*



Source: Extrapolated from Global Forest Resources Assessment 2015 (FAO 2015)

rates of planted forest expansion. Of concern was an apparent drop in the rate of new planted forests in the period 2010–2015 to 1.2 percent per year. It has been estimated that the rate of increase of 2.4 percent per year was needed to meet future global demand and supply of wood and fibre and thus offset deforestation impacts on wood supply (Payn *et al*. 2015).

The top planted forest resources reported in 2015 in order by area (millions hectares) in each region by selected key countries included: Sudan (6.1), South Africa (1.8), Ethiopia (1.0) in the African Region; Russian Federation (19.8), Sweden (13.7), Poland (9.0), Finland (6.8) and Germany (5.3) in the European Region; Brazil (7.7), Chile (3.0), Argentina (1.2), Peru (1.2) and Uruguay (1.1) in the Central, South American and Caribbean Region; USA (26.4) and Canada (15.8) in the North American Region; New Zealand (2.1) and Australia (2.0) in the Oceania Region; and China (79.0), India (12.0), Japan (10.3), Indonesia (5.0), Ukraine (5.0) in the Asian Region (FAO 2010a, 2015).

TABLE 1 *Regional and global planted forest area*

Year	Regional and Global Planted Forest Areas (000 ha)						
	Africa	Europe	Central & South America	North America	Oceania	Asia	Global Total
1990	11705	55445	8818	22516	2741	74868	176093
2000	12796	63186	10503	31905	3460	96380	218230
2005	13929	70513	11521	36135	3988	114365	250451
2010	15355	78987	14506	39539	4225	124559	277171
2015	16329	80709	16195	42148	4357	133669	293407

Source: Extrapolated from Global Forest Resources Assessment 2015 (FAO 2015)

Planted forest species

There was a predominance of indigenous or native species plantings for production and protection forests in northern hemisphere countries whilst there is a predominance to plant introduced or exotic species for production plantings in southern hemisphere countries. Selected countries in the northern hemisphere that have significant planting of both indigenous and introduced species include Morocco, Senegal and Tunisia in the African Region; Albania, Denmark, France, Ireland, Portugal and Spain in the European Region; China, India, Iran and the Republic of Korea in the Asian Region. In comparison, in the southern hemisphere, Australia is the only country that planted about half in indigenous species and half in introduced species (FAO 2015). Figure 4 displays the percentage of introduced species by area in planted forests by region.

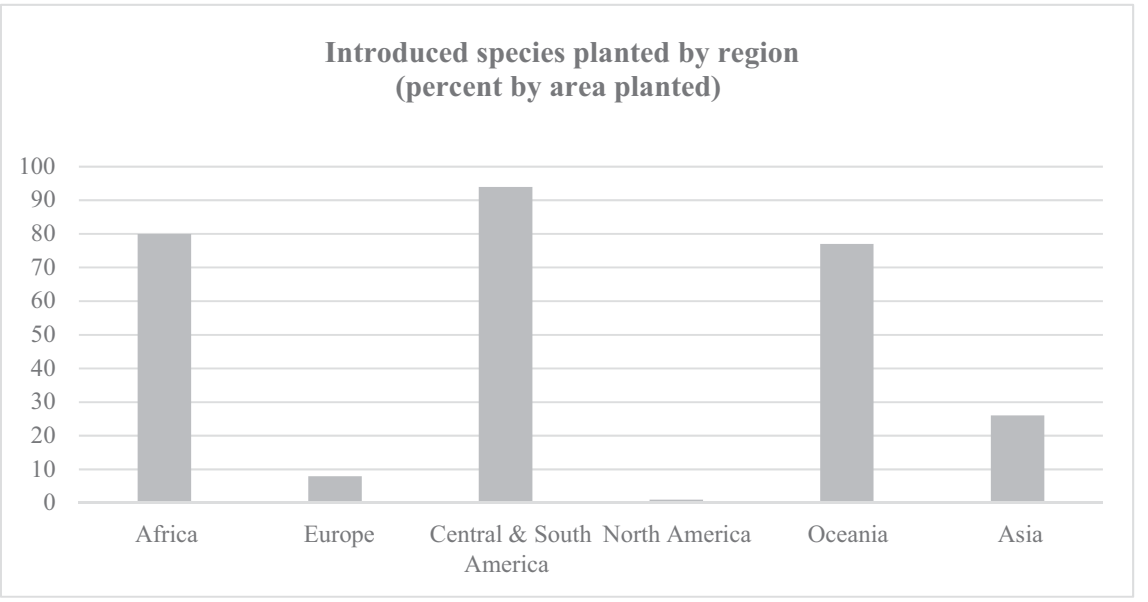
In the global assessment of planted forests, although not a comprehensive list, the main species reported by countries are detailed in Table 2 (FAO 2006a):

Ownership of planted forests

Between 1990 and 2005 public ownership of planted forests for productive purposes went from 70 percent in 1990 to 54 percent in 2000 and 50 percent by 2005. The private corporate ownership increased marginally from 17 percent in 1990, to 19 percent in 2000 and 2005. However, smallholder private ownership of planted forests increased from 12 percent in 1990, to 27 percent in 2000 and 32 percent by 2005. Although some variation was shown by different regions the overall trends were consistent (FAO 2006a).

In 1990 the public sector owned 82 percent of planted forests grown for protective purposes, but this proportion reduced to 73 percent by 2005. In 1990 the private corporate ownership was 8 percent and in 2005, 7 percent. However, the private smallholder ownership increased from 9 percent in 1990 to 20 percent in 2005 (FAO 2006a).

FIGURE 4 *Planted forests: introduced species planted by region*



Source: Extrapolated from Global Forest Resources Assessment 2015 (FAO 2015)

TABLE 2 *Main planted forests species planted by region*

Region	Main Species
Africa	*Acacia mellifera, A. nilotica, A. senegal, A. seyal, Eucalyptus grandis, E. nitens, Eucalyptus* spp., *Pinus elliottii, P. halepensis, P. patula, P. radiata*
Europe	*Betula pendula, Fagus sylvatica, Larix decidua, Picea abies, Picea sitchensis, P. nigra, Pinus pinaster, P. sylvestris, Populus* spp., *Pseudotsuga menziesii, Quercus robur, Robinia pseudoacacia*
Central and South America and Caribbean	*Eucalyptus* hybrids, *P. elliottii, Pinus radiata, Pinus taeda, Prosopis tamarugo* and *P. chilensis*
Oceania	*Eucalyptus globulus*, *Hevea brasilensis, Pinus radiata, Pinus* spp., *Swietenia* spp.
North America	*P. elliottii, Pinus taeda, Populus tremuloides*
Asia	*Acacia* spp., *Casuarina* spp., *Chamaecyparis obtusa, Cryptomeria japonica, Cunninghamia lanceolata, Eucalyptus* spp., *Hevea brasilensis, Larix kaempheri, Pinus massoniana, Pinus* spp., *Populus* spp., *Tectona grandis*

Source: Global planted forests thematic study: Results and analysis (FAO 2006a)

Governance of planted forests

Although there have been challenges with laws, regulations and policies relating to planted forests and trees in developing countries, inadequate implementation and monitoring of compliance was often an even greater challenge. Weak governance and political and economic instability resulted in high transaction costs that affected risk factors and the confidence to invest in planted forests (Barua *et al*. 2014).

A major study coordinated by FAO in 2003 evaluated the direct and indirect incentives and policy instruments that encouraged investments in planted forests in Australia, China, India, Indonesia, Malaysia, New Zealand, the Philippines, Thailand and USA. Although comparisons between countries were broad due to the contextual differences there was a general evolution in the types of incentives offered at different planted forest development stages. In all case study countries, the Government owned planted forests on State land at the outset to demonstrate planted forest silvicultural techniques and to achieve a critical mass to demonstrate the production and utilization of planted forest wood that stimulated private sector and smallholder interest to invest. Enabling the private sector (both corporate and smallholder) resulted in a gradual policy progression from providing free physical inputs; to grants and loans; to tax incentives; to joint venture arrangements; and finally, to creating an enabling policy, legal and regulatory environment and removing structural disincentives (Enters *et al*. 2004). Table 3 synthesizes case study country incentive reports.

TABLE 3 *Progression of policy incentives in planted forest case study countries*

Country	State planting	Cheap seedlings	Land grants	Nursery subsidies	Survival incentives	Grants to growers	Concessionary loans	Tax concessions	Joint ventures	Research + extension	Resource security	Enabling incentives
Australia	✓						✓	✓	✓	✓	✓	High
China	✓	✓				✓	✓			✓	✓	Medium
India	✓	✓	✓	✓	✓	✓	✓		✓	✓		Low
Indonesia	✓					✓	✓	✓		✓		Low
Malaysia	✓							✓		✓		Medium
NZ	✓	✓	✓			✓	✓	✓	✓	✓	✓	High
Philippines	✓		✓					✓				Low
Thailand	✓	✓				✓	✓			✓		Low
USA	✓	✓	✓			✓	✓	✓	✓	✓	✓	High

Source: Enters *et al*. 2004

Enabling national policies for planted forest development have occurred in South America (Brazil, Chile and Uruguay); Asia-Pacific (Australia, China, Malaysia, New Zealand and Vietnam) and Europe (United Kingdom, Spain and Portugal), there has been less use of incentives and enabling policies in governance of planted forests in the African region other than South Africa and Uganda (Forest Stewardship Council [FSC] *et al*. 2012).

The enabling incentives have included legal, policy, regulatory and institutional frames that encouraged investment and which have had cohesive and clear land, land use and crop ownership rights; responsible social and environmental safeguards; free and transparent access to markets to increase forest products values; transfer of research knowledge and technology through technical support and extension services to sustain productivity and sustainability; recognize the role that planted forests can play in mitigating the effects of climate change and disaster risk reduction; reduce biotic, abiotic and market risks; providing access to funds and fair markets; and building trust between partners and committing to transparent and equitable agreements were fundamental to the success of planted forests investments, particularly smallholder planted forests (Barney 2008, Nguyen 2011, Midgley *et al*. 2017, INDUFOR 2017, Nambiar *et al*. 2014, Nambiar 2019).

Government investment in planted forests

In the past Government investment in planted forests was to demonstrate to the private sector and smallholders how to grow a valuable forest resource for the wood industries sector to provide a range of products to consumers whilst substituting for the exploitation of indigenous forest resources. As Governments generally had insufficient resources to establish and manage planted forests, they often borrowed from development banks to do so. Lessons learned from past challenges showed that without enabling policy, legal and regulatory frames and sound technical and extension capacity, identified markets and financial and human resources to support these investments, then the results were socially, environmentally and economically suboptimal. The global reduction in government ownership of planted forests has occurred due to devolution of forest management to the private sector, forest communities and smallholder investors; the disappointing performance of Government owned planted forests; and the budget and human resource constraints. As a result, Governments have generally been increasingly focused on providing the enabling policy, legal and regulatory instruments and supporting institutional arrangements to encourage investment by alternative investors (Enters *et al*. 2004). The proportion of Government ownership of planted forests is likely to continue to decline in the future as investments by the private sector (corporate and smallholder) increase.

International investment in planted forests

An analysis of 40 plantation forest investments around the globe had international rates of return in excess of 5 percent without land costs. In about half the cases profits were made by buying land and growing wood from planted forest at an 8 percent discount rate. In industrialized, temperate countries planted forest investments yielded lower rates of return but were competitive with other land uses and stock market returns. In developing countries and countries in economic transition with higher levels of political and investment risk, more difficulty in doing business and more environmental regulation and transaction costs could yield the highest rates of return but investments were less predictable or assured than in industrialized countries (Cubbage *et al*. 2014). As Brazil and China have substantial domestic demand and market diversification so they have less dependence on export markets. New private sector, international investment fund opportunities are being sought in Brazil, Colombia, Ecuador, Uruguay and countries in Southeast Asia and Africa where land prices and cheaper labour can make potential returns on investment higher, as can the risks (Cubbage *et al*. 2014).

Finding the balance between investment returns and risks, difficulty of doing business, maturity and diversity of markets and the political and enabling stability will continue to challenge and reward forest investors and managers through the 21st Century (Cubbage *et al*. 2014). Although the level of international corporate investment in planted forests has increased significantly in recent decades the proportion (percentage by area) has remained similar at 17–19 percent (FAO 2006a). If Governments put in place enabling conditions for investment and particularly planted forest investment, the proportion of corporate private sector investment is likely to increase particularly in Asia and Central and South America.

Smallholder investment in planted forests

Smallholder investment in planted forests and trees already make a substantial contribution to national forest assets, wood production, exports, national incomes and in meeting sustainable land use and livelihoods of rural people. The contribution that smallholder investors make to economic development is grossly underestimated as the scattered, small holdings are difficult to survey accurately and harvesting does not always follow conventional silviculture, but rather meets livelihoods needs. Finland, Sweden, China, India, Indonesia, Vietnam, Malaysia, Thailand, Lao PDR, the Philippines, Brazil, Chile, Uruguay, Costa Rica, New Zealand, USA, Uganda, Mozambique, Rwanda, Swaziland, Tanzania, Zambia, South Africa, Ethiopia have, or are developing more robust smallholder investments in planted forests. Smallholder investment in planted forests has often been in response to successful incentive schemes to develop a critical mass of forest resources to establish forest-based industries, catalyse socioeconomic development, reduce poverty in rural areas, reduce pressure on natural forest resources and strengthen land tenure (FAO 2006a).

The recent expansion in smallholder investment in planted forests (both productive and protective purposes) and the promising future for continued expansion requires collaboration between the partners that include smallholders and their governments, financiers, industries and research and extension organizations. It is the authors' view that the proportion of smallholder planted forests and trees is likely to

continue to expand due to the availability of land, the potential returns of planted forests to supplement other smallholder income in rural areas and the contributions that planted forests make towards improving water quality and hillside erosion protection.

FUTURE ROLE OF PLANTED FORESTS

Guidance from international processes

International congresses in Chile (IFF 1999), New Zealand (UNFF 2003), Portugal (FAO *et al*. 2013) and China (FAO *et al*. 2018) brought specialists together to discuss topical issues and to provide guiding principles and strategic implementation practices to planted forest stakeholders on enhancing the future role of planted forests in sustainable forest management, green economies and restoration of landscapes.

Various guidelines for responsible management of planted forests were prepared through multi stakeholder processes and associated capacity building by international agencies (FAO, ITTO, CIFOR) and at the country level by both the public and private sectors to enhance the role of planted forests in the social, cultural, environmental and economic dimensions of landscape management and sustainable livelihoods and land use (FAO 2006b, CIFOR 2005, ITTO 1993). The guidelines were transposed into country and company specific policy, legal, planning and implementation contexts.

The role of planted forests in industrial roundwood production

During the past two decades, several global outlook studies have compared the future role of planted forest resources in industrial roundwood production (ABARE-Jaakko Poyry 1999)[1]; Brown 2000)[2]; (Carle and Holmgren 2008)[3]; (Penna 2010)[4]; FSC and INDUFOR 2012)[5]; FAO 2014)[6].

Outlook studies are used by policy and decision makers, investors, managers and planners to better understand the role that planted forest resources can play in the production, utilization and trade of forest products. As the 1999, 2000, 2008 and 2012 outlook studies were based on different definitions, datasets, growth and yield models, assumptions and modest, moderate and optimistic scenario analyses the results are not directly comparable, however, they can provide trends and indicative ranges of results. The estimated global industrial roundwood production in 2012 from plantation forests was estimated conservatively at 562 million m^3 or 33 percent and the planted component of seminatural forests at 208 million m^3 of the 1.7 billion m^3 global industrial roundwood production from all types of forests. The total global production of industrial roundwood from planted forests (plantation forests + planted component of seminatural forests) was estimated at 770 million m^3 or almost half (46 percent) of the 1.7 billion m^3 of industrial roundwood production from all types of forests in 2012 (FAO 2014).

The results for the modest, moderate and optimistic scenarios of the above outlook studies for plantation forests (according to the forest plantation definition prior to 2005) are given in Figure 5 and for planted forests (according to the new definition 2005) in Figure 6.

Based upon the Global Forest Resources Assessment (GFRA) 1990 data updated to 1995 and the definitions of the time, the ABARE outlook estimate of 116 million hectares of productive plantation forests in 2000 the industrial roundwood production was forecast at 624 million m^3 or 35 percent of global industrial roundwood production in 2000; 969 million m^3 or 44 percent in 2020 and 1,043 million m^3 or 46 percent in 2040 (ABARE and Jaakko Poyry 1999).

Also based upon the GFRA 1990 and definitions of the time, the FAO/Brown outlook estimated 124 million hectares of productive plantation forests would yield 22 percent of global industrial roundwood production in 1995, up to 34 percent in 2010, up to 46 percent in 2020 and up to 64 percent in 2050 (Brown 2000).

The Penna outlook study based upon the global planted forests thematic study data (FAO 2006a) and Carle and Holmgren study 2008 forecast that plantation forests could yield 736 million m^3 of industrial roundwood or 41 percent of global industrial roundwood in 2005 and up to 1,401 million m^3 or 77 percent in 2030 (Penna 2010).

The FSC outlook forecast, based upon the INDUFOR fast growing plantation forest datasets, estimated 520 million m^3 of industrial roundwood from their dataset of industrial plantation forests or 31 percent of global industrial roundwood production in 2012 and up to 2.0 million m^3 by 2050 (FSC and INDUFOR 2012).

The Carle and Holmgren outlook forecast, based upon the global planted forests thematic study data, estimated a global area of 271 million hectares of planted forests consisting 128 million hectares of plantation forest and 133 million hectares of planted component of seminatural forests. The industrial roundwood production potential from planted forests was 1,220 million m^3 or 66 percent of global industrial roundwood production in 2005 and up to 1.9 million m^3 in 2030 (Carle and Holmgren 2008 and Penna 2010).

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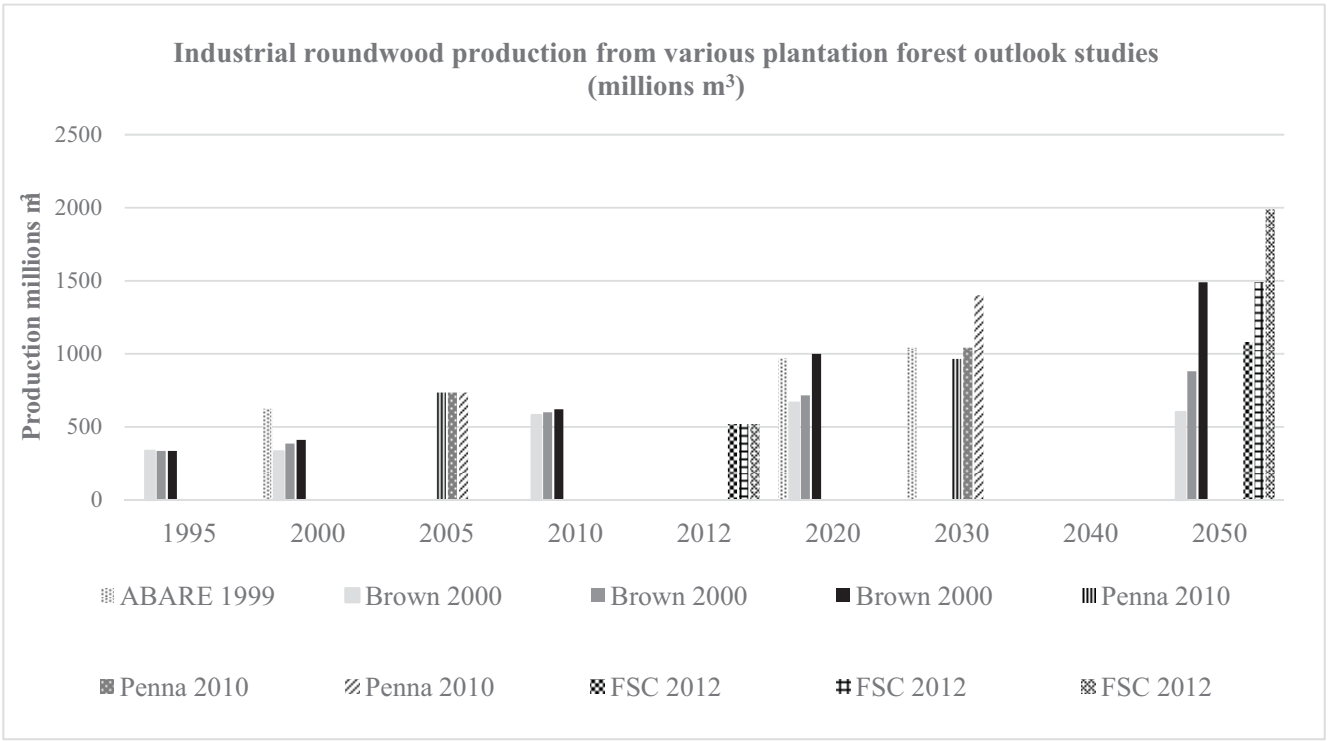
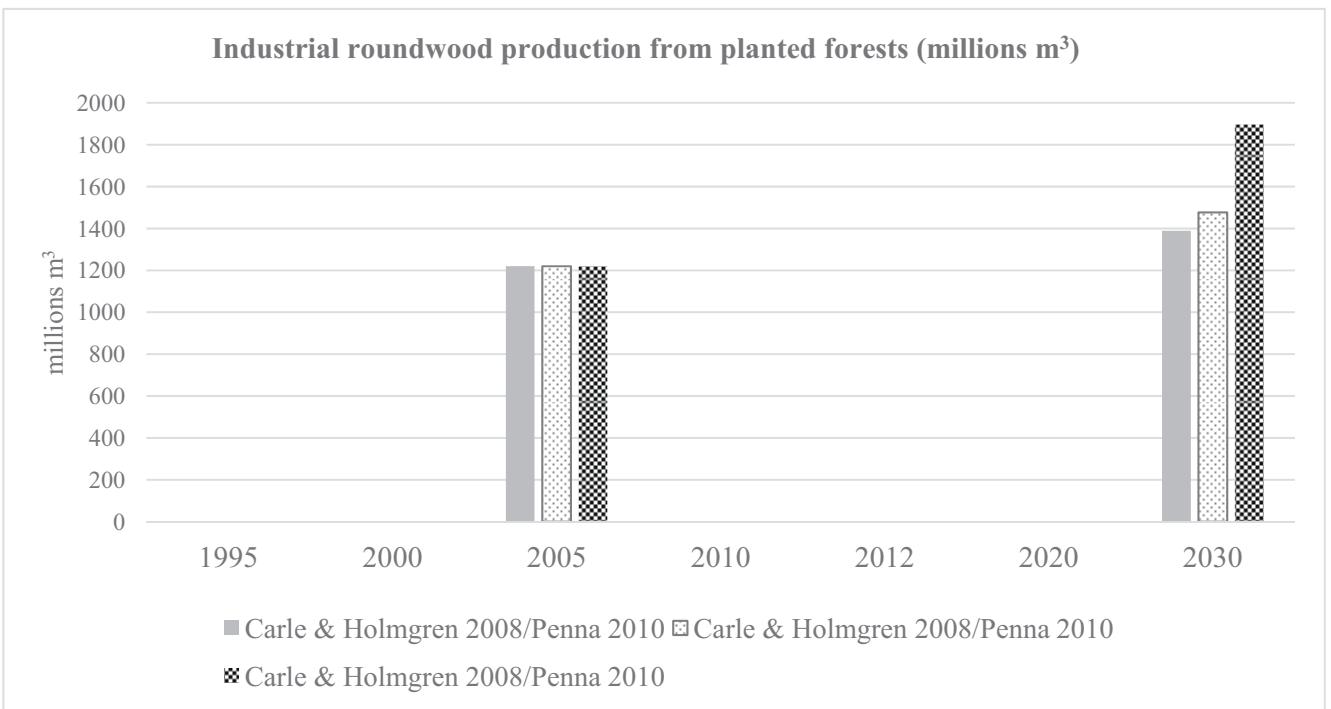
[1] Global outlook for plantations (ABARE-Jaakko Poyry 1999) http://www.fao.org/forestry/42688-0a52e579757b86dd833ee20ba6e567078.pdf
[2] Global outlook for future wood supply from forest plantations (Brown 2000) http://www.fao.org/3/X8423E/X8423E00.htm
[3] Wood from planted forests: A global outlook 2005–2030 (Carle and Holmgren, 2008) http://www.fao.org/forestry/24492-0d26e5849f963ec2846872435fe0777c2.pdf
[4] Understanding FAO's wood supply from planted forests projections (Penna 2010): http://www.fao.org/forestry/42642-0aad8396ff459da7a9accf941e567ebb5.pdf
[5] Strategic review on the future of forest plantations (FSC and INDUFOR 2012): http://www.fao.org/forestry/42701-090e8a9fd4969cb334b2ae7957d7b1505.pdf
[6] Assessment of industrial roundwood production from planted forests (FAO 2014): http://www.fao.org/3/a-i3384e.pdf

FIGURE 5 *Comparison of Industrial roundwood production from various plantation forest outlook studies (plantation definition prior to 2005)*



Source: Author compilation from outlook studies

FIGURE 6 *Industrial roundwood production from planted forests*



Source: Author compilation from outlook studies with planted forests definition 2005+

The outlook studies conclude that despite the variation in results planted forests will continue to have an increasing role in the production of industrial roundwood globally towards the mid-21st Century. These highlight the importance of planted forests as the planted forest resources continue to expand whilst indigenous forest resources decrease due to deforestation or forest degradation on the one hand, or being designated for protection or conservation management purposes on the other.

KEY INFLUENCES ON THE FUTURE ROLE OF PLANTED FORESTS

Mitigating the effects of Climate Change

Expanding new planted forests to sequester and store carbon is an effective and economic way to rapidly reduce carbon dioxide from the atmosphere. Planted forests can provide multiple benefits as a reliable, renewable and climate-positive source of wood, fibre and fuel and ecosystem services, including reduction in greenhouse gas emissions and support the transition to a sustainable green, circular, bioeconomy. Forest restoration and reforestation remain the most effective strategies to mitigate the effects of climate change. It is estimated that there is potential for an additional 0.9 billion hectares of forest canopy cover globally that could store an estimated 205 giga tonnes of carbon (Bastin *et al*. 2019).

It has been estimated that natural climate solutions such as improved conservation, restoration, reforestation and expanded afforestation and improved land management can provide over a third of the cost-effective climate mitigation solutions needed by 2030. About a half of the land available globally for afforestation and reforestation is on the African continent where planted forests can potentially create positive social, environmental and economic benefits, however, this investment has yet to materialize, despite the Bonn Challenge[7] and the AFR100[8] target to restore 100 million hectares of deforested and degraded land across the continent by 2030. Responsibly managed planted forests integrated into the landscape provide opportunities to increase the supply of renewable raw materials, restore degraded ecosystems to build resilience and create value for people living nearby (Jeffries *et al*. 2018).

The global meeting hosted at FAO in 2017 on "Sustainable Wood for a Sustainable World[9]" concluded that sustainable wood chains were relevant for all 17 of the Sustainable Development Goals[10], especially for decent work and economic growth, SDG8; responsible consumption and production, SDG12; climate action, SDG13; and life on land, SDG15 (FAO 2017).

New technology

Countries in Europe, North America, Central and South America and Oceania have been leaders in the science and technology of plant breeding, gene mapping, genetic improvement, site-species matching, near to nature plantings, advanced silviculture and harvesting, maintaining sustainable productivity and the adaptation to climate change. It is the authors' view that the use of computers, particularly hand held computers, custom made software, unmanned aerial vehicles (drones), driverless vehicles, and satellite based systems are revolutionizing forest planning, management, monitoring, e-mapping, GIS database management and information systems, innovative new harvesting and transport systems, supply chain management, forest risk management and marketing, robotics and driverless harvesting and transport systems.

New green, circular bioeconomy technologies applied in planted forests will spread to all regions around the world. As a result, reforestation and new plantings will generally not only sustain current levels of productivity but likely, through improved management, increase growth and harvest yields and shorten rotation lengths so that wood, fibre and fuel will be produced more efficiently, despite the impacts of climate change and the associated impacts of insects, diseases, pests, fire and other biotic and abiotic agents (Payn *et al*. 2015).

Innovations in the use of wood

There is a renaissance in the use of wood in recognition that it is a renewable, environmentally neutral (if responsibly managed), resilient construction material that can be used for creative architecture and building purposes by adopting new wood technologies that open new opportunities for innovative designs and construction methods. With a growing global population and demand for wood products, the need for process innovations to minimize waste, minimize production costs and maximize yield will continue into the future. Societal demand for more natural, sustainable and renewable products is driving innovation in the 21st Century wood products industry (World Bank 2019).

New wood products and initiatives are promoting the use of wood as an alternative to concrete, steel, aluminium, plastic and other building materials with a much bigger carbon footprint (World Bank 2019). Architect, Alex de Rijke, director of London-based firm dRMM, recently noted that that *"the 17th century was the age of stone; 18th century was the peak of brick; the 19th century the era of iron; the 20th century the century of concrete and the 21st century will be the time for wood"*[11]. Increasingly a higher proportion of wood will be from sustainably managed and legally sourced

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[7] http://www.bonnchallenge.org/content/challenge
[8] https://afr100.org/content/about-us
[9] http://www.fao.org/forestry/46700-0a274f69ab292a75be6ef89e8c4aa7566.pdf
[10] https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[11] Alex de Rijke, director of London-based firm dRMM, November 2015: See: https://www.dezeen.com/2015/11/09/cross-laminated-timber-construction-architecture-timber-age/

planted forest resources as verified by FSC, Programme for the Endorsement of Forest Certification (PEFC) or other reputable, third party forest management and chain of custody certification or through Forest Law Enforcement Governance and Trade (FLEGT) approved voluntary partnership agreements with timber legality assurance systems for entry into European countries (World Bank 2019).

We are familiar with the traditional forest products like timber, structural panels, newsprint, pulp, paper and packaging. By breaking wood down to central components of cellulose, hemi-cellulose and lignin a whole range of new products are possible. Bath towels and disinfecting wipes produced from rayon are mainly cellulose; toothpaste and make up from carboxymethyl cellulose and xylitol; nail polish, leather finishes, ping pong balls, wood varnishes and printing inks are from nitrocellulose; many medications contain the wood component microcrystalline cellulose; many paints contain hyrdroxyethyl cellulose a gelling and thickening agent; LCD electronic screens contain wood component cellulose triacetate which acts as a polarizing film; wood based polyethylene terephthalate is used for soft drink bottles. Wood fibre has the potential to play a major role in providing lignin-based substrate for 3D printers as an affordable and renewable by-product of pulp mills. Liquid wood, an alternative to plastic is a thermoplastic material made from lignin as a by-product of pulping. Bioactive compounds from wood can be used for antibiotics, antioxidants and pesticides. Bio-oil can be produced from fast pyrolysis for industrial heating. Nanomaterials are being used in the textile industry to waterproof and make tear-resistant fabrics; when added to concrete to add tensile strength and in air filters and solar cells. Wood modification without chemicals through application of heat can alter the chemistry of wood to make it more durable and stable so that it can be used for decking, doors, windows, spas, saunas, fencing, outdoor furniture etc. Cross-laminated timber (CLT) gives strength in green building whilst exciting architects for innovative designs and multi-story wood construction which store carbon long-term. Stora Enso calculated that CLT panels can store 730kg of carbon per cubic metre (Jeffries 2018).

All these innovations in wood products and a growing movement towards a green, circular bioeconomy, lead to the fact that the demand for wood-based products is going to increase and therefore the proportion from planted forests will increase to grow more wood, fibre and fuel faster.

Competition for land

Planted forests are less than 2 percent of land use globally but vary considerably from country to country around the globe. It is anticipated that planted forests land use could double by 2050. Although they will produce the majority of global wood supply, they will generally not be the main form of land use in rural landscapes. Because of population, livestock and grain growth, increased food and associated agricultural demand and the evolving expansion in demand for bioenergy, planted forests compete for access to suitable land that will put pressure on land prices. As a result planted forests will increasingly be established in lands marginal for agricultural purposes that will require improved germplasm, management systems and technologies that will result in higher sustainable productivities to address social, environmental and economic challenges (FSC *et al*. 2015, Payn 2015).

As an alternative to establishing new planted forests in agricultural lands, in some instances, improved investment and management can improve the productivities and efficiencies of existing planted forests. A study of twenty-two plantation projects in ten African countries compared capital investments and performance between greenfield plantations established in bare land; brownfield plantations acquired and rehabilitated to improve their productivity; and smallholder plantations, often community based. Greenfield plantations were found to be expensive to develop and commercial financing was difficult to secure. Brownfield plantations, often owned by governments, showed the potential to increase wood supply through improved management to increase productivity through privatization reform that attracted responsible investors to purchase and manage these plantation forests more efficiently. Smallholder plantations were established cost effectively with diversified species and age classes resulting in positive development and climate impacts, particularly if linked to larger commercial plantations and wood processing industries (Criterion and INDUFOR 2017).

Environmental issues

In instances of good governance, the appropriate interlinked environmental and social policies, laws, regulations and guidelines were implemented and monitoring of compliance was undertaken. However, when weak governance exists, the reverse generally occurs. With appropriate planning and management, planted forests can be managed for resilience to climate change by diversifying the mosaic of land uses on the landscape, diversifying species, doing better site and species matching, undertaking regular forest protection and staggering harvesting coupes to fragment cutovers exposure. Planted forests also mitigate climate change by carbon sequestration, carbon sinks (above and below ground) and storage of carbon in wood products (World Bank 2019).

There is likely to be an increased risk of extreme weather events (winds, floods, droughts, extreme temperatures etc.) and associated vulnerability to insects, pests, diseases, wildfires and invasive plant species so the use of new technologies for monitoring, early warning, prevention, preparedness, emergency response and restoration following such events will be critically important to minimize impacts (Dell *et al*. 2012). Minimizing monocultures and narrow genetic base of planted forests (single or a few clones) can reduce vulnerability to biotic and abiotic risk factors. In habitats that experience seasonal drought, there are concerns that planted forests exacerbate water shortages that impact local communities as reported in South Africa and Ethiopia. Conversion of indigenous forests to establish planted forests is not an environmentally or socially responsible option and should be avoided. Responsible management of planted forests can minimize any negative environmental impacts and in some

instances of landscape restoration, can enhance the environmental impacts (FAO 2006b, Payn *et al*. 2015). Planted forests can contribute positively to forest conservation and reduce forest degradation of indigenous forests, however, good governance is necessary to minimize the risk of displacement effects and associated deforestation to maintain livelihoods in poor communities (Pirard *et al*. 2016).

Social issues

Population pressure for food security, poverty reduction and sustainable livelihoods, particularly in Africa and Asia, resulted in greater competition for land, that impacted access to land for planted forests. The lack of clarity between the statutory and customary (traditional) land use rights generally resulted in social tensions between planted forest investors and owners and the local communities, unless participatory and transparent processes were adopted. This has been common in Asia, the Pacific, Africa and South America where indigenous peoples have depended upon their customary rights for access to resources for their livelihoods that have overlapped with company agreements with statutory rights granted by the government. As a result, companies needed to resolve conflicts with local communities before planted forests could proceed successfully (Barney 2004, Lexterra 2016, Malkamaki *et al*. 2018).

It is the authors' view that failings of planted forests in the past have resulted in negative public biases against planted forests as a legitimate land use, so there is a need for planted forest investors to be more participatory, transparent and communicative with not only the key stakeholders, but also the general public.

Between 1990–2015 Europe had minimal population growth and a 37 percent increase in planted forest area; Central America had a 45 percent increase in population with a 17 percent increase in planted forest area; whilst Southern and Southeast Asia had large increases in both population and planted forests so land and future wood supply pressure is likely to be more intense (Payn *et al*. 2014). This trend is likely to continue particularly in countries with green growth economic policies in which society is increasingly demanding more wood, fibre, fuel and non-wood forest products and ecosystem services from responsibly managed, high productivity and sustainably managed planted forests.

Expansion of the global planted forest resource

The rate of expansion of planted forests 1990–2015 was 2.7 percent per year (176.1 to 293.4 million hectares), however, from 2010–2015 the rate lowered to 1.2 percent per year (FAO 2006a). The authors estimated that based upon maintaining the expansion rate of 2.7 percent the planted forest resource in 2020 would be 335.2 million hectares, by 2025, 383.0 million hectares and by 2030, 437.5 million hectares. Using the more conservative rate of expansion of 1.2 percent per year the planted forest resource in 2020 would be 316.5 million hectares, by 2025, 335.9 million hectares and by 2030, 355.5 million hectares. It is anticipated that the planted forest resource could double by 2050 (FSC *et al*. 2012, Payn *et al*. 2015).

The market demand for planted forest wood is increasing substantially, so the rate of expansion will depend heavily on the rate at which governments can adopt clear and cohesive policy, legal, regulatory and institutional frames; grant rights to available and accessible land without ownership conflicts and major environmental constraints; and encourage partnership agreements with clear statement of inputs, responsibilities, risks, and benefits. Additionally, the impacts of market dynamics and new technologies and biotic and abiotic risk factors, exacerbated by extreme weather events and climate change and the transfer of knowledge and technology from scientific research to development of planted forests will play critical roles (Payn *et al*. 2015).

The planted forests of the future will not replicate those of the past that focused heavily on wood production. Some planted forests will be managed for wood production but increasingly they are being managed for multiple purposes to provide a sustainable supply of wood products as well as a combination of ecosystem services such as conservation of biodiversity, sequestration and storage of carbon, soil and water protection, restoration of degraded landscapes, or recreation and amenity functions that provide alternative financial return options to investors through payment for ecosystem services (Maginnis *et al*. 2003).

Lessons learned

Some key lessons learned to enhance the role of planted forests:

- Planted forests require the critical enabling policy and legal frames that provide the security for private sector investment and clear and secure rights for land use and crop ownership, management harvesting, marketing and trading forest products.
- Planted forests have social and environmental impacts that require clear stakeholder participation, transparency and partnerships in planted forest investments.
- Planted forests have roles in reducing poverty, enhancing food security and sustainable livelihoods with responsible investments, planning and management.
- Planted forests can play critical roles in rehabilitation of degraded lands and provide ecosystem services, particularly carbon sequestration.
- Planted forests can be integrated into the mosaic of multiple land uses in landscape approaches.
- Planted forest resilience to biotic, abiotic and market risks can be enhanced by preventive operational practices, species diversity and silviculture to maintain stand productivity, vitality and viability.
- Planted forests can provide a wide diversification of forest products including traditional products, bioenergy and a wide range of new bio products.
- Planted forest investors can enhance their access to discerning markets that require proof of sustainability and legality through forest certification and legality verification.

Challenges and Opportunities

Population growth, competition for land, climate impacts, societal perceptions and governance which affect investment and management will remain significant challenges in the future of planted forest development. Protection of planted forest crops from insects, diseases, other pests, invasive species and wildfire, exacerbated by extreme weather events will remain a challenge to maintaining productivity and harvest yields. Access to forest certification will remain a challenge for planted forests owned by communities and smallholders until the certification systems revise their principles, standards and procedures (World Bank 2019).

Improved silvicultural management, brownfields investments, genetic improvement, increased focus on forest protection, social inclusion and new innovations in harvesting, transport and wood products processing for planted forest products are likely to increase the management options, financial performance and investment in productivity, health and sustainability in planted forests. The use of forest certification and legality verification schemes and the new generation planted forests platform will encourage responsible and inclusive management and more positive societal knowledge of the future role of planted forests in providing not only wood, wood based, fibre and fuel products but a range of critical services (Payn *et al*. 2015; Criterion and INDUFOR 2017).

Conclusions

Planted forests are likely to continue to expand and provide the social, environmental and economic benefits if good governance sets the stable enabling conditions for planted forest investments, including legal, policy, regulatory and institutional frames that encourage investment through cohesive and clear land, land use and crop ownership rights; responsible social and environmental safeguards; free and transparent access to markets to increase forest products values; transfer of research knowledge and technology through technical support and extension services to sustain productivity; recognize the role that planted forests can play in mitigating the effects of climate change and disaster risk reduction; reduce biotic, abiotic and market risks; providing access to funds and fair markets; and building trust between partners and committing to transparent and equitable partnership agreements.

The proportion of Government ownership of planted forests is likely to continue to decline in the future as investments by the private sector (corporate and smallholder) increase; corporate private sector investment is likely to increase particularly in Asia and Central and South America; and smallholder planted forests are likely to continue to expand due to the availability of land and the potential returns of planted forests to supplement other smallholder income in rural areas. Ownership and tenure of planted forests will be more diversified than in the past and will include a mix of financial investors, private smallholder and medium sized growers; lease arrangements between governments and companies; partnerships between strategic and financial investors as well as between companies and local landowners.

New green, circular, bioeconomy technologies applied in planted forests will spread to all regions around the world. As a result, reforestation and new plantings will generally not only sustain current levels of productivity but likely increase growth and harvest yields and shorten rotation lengths so that wood, fibre and fuel will be produced more efficiently and sustainably. There is a renaissance in the use of wood in recognition that it is a renewable, environmentally neutral, resilient construction material that can be used for creative architecture and building purposes by adopting new wood technologies that open new opportunities for innovative designs and construction methods. Additionally, by breaking wood down to central components of cellulose, hemicellulose and lignin a whole range of new innovative bioproducts are possible so that the demand for wood based products are going to increase substantially and the proportion from planted forests will need to increase to grow more wood, fibre and fuel faster.

It has been forecast that planted forests could increase from under 2 percent of global land use to about 4 percent by 2050. Because of population and livestock growth, increased food and associated agricultural demand and the evolving expansion in demand for bioenergy, planted forests will compete for access to suitable land that will put pressure on land prices and result in planted forests being established in marginal agricultural lands, adopting improved germplasm and management systems and adopting technologies that will result in higher sustainable productivities and adopting participatory process and partnerships to address social and environmental challenges.

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