Assessment of Biomass and Carbon Storage for the Teak Plantation by MPRVVN under CSR of Havells India Limited

Center for Climate Change Studies
Geo-Informatics Center for Forestry, Climate Change and Livelihoods
Indian Institute of Forest Management, Bhopal

Assessment of Biomass and Carbon Storage for the Teak Plantation by MPRVVN under CSR of Havells India Limited

Project Team

Dr. Bhaskar Sinha (Team Leader)

Dr. Jigyasa Bisaria

Dr. Bhimappa Kittur

Shimali Chauhan

Shiv Narayan Singh

Center for Climate Change Studies

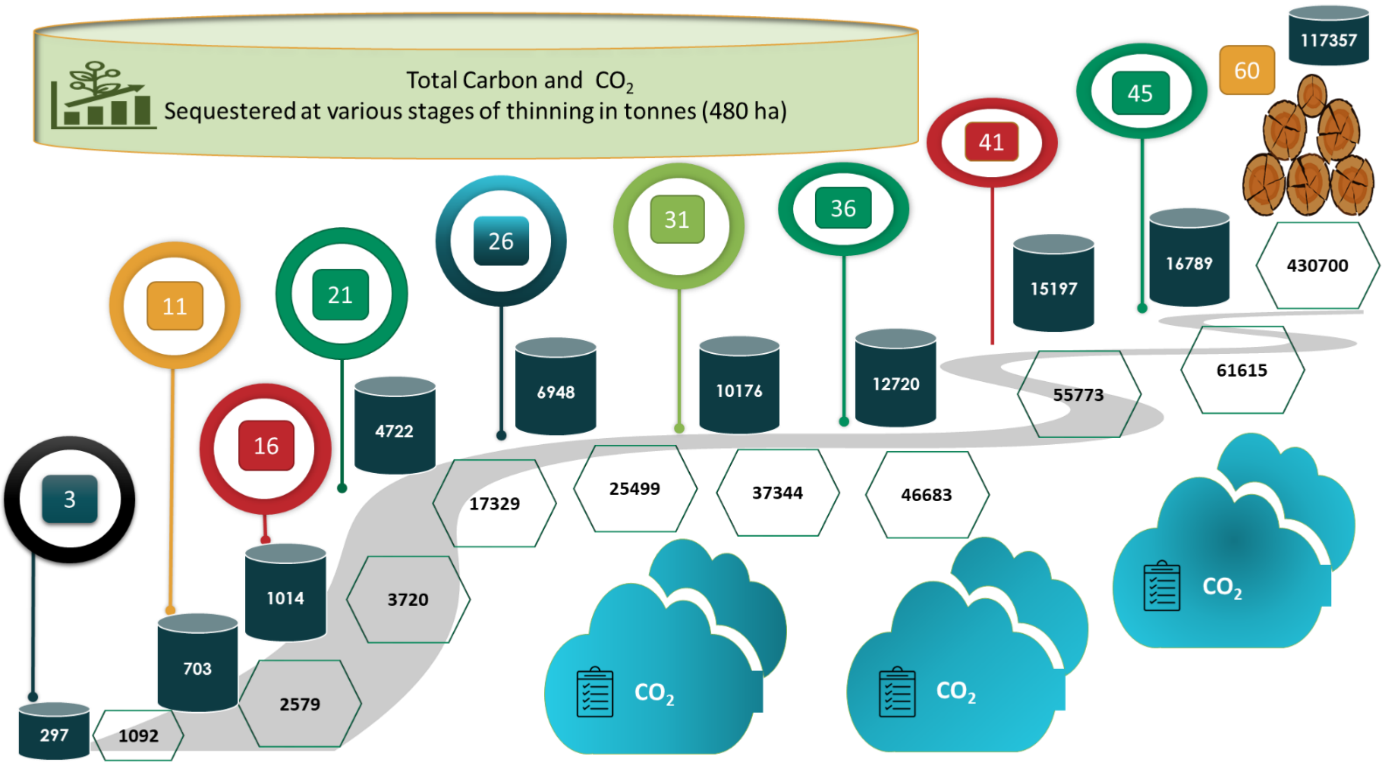
Geo-Informatics Center for Forestry, Climate Change and Livelihoods

Indian Institute of Forest Management, Bhopal

Table of Content

Executive Summary

With the support of Havells India Ltd., MPRVVN has done plantation in 690 ha between 2018 and 2022 in the Vidisha, Sehore and Sagar divisions of Madhya Pradesh. IIFM has assessed the survival and carbon dioxide sequestration potential of the plantation in 480 ha, done between 2019-2021. The survival rate of the plantation is more than 90% across the compartments, which is reflective of good management. The total CO_2 sequestered so far in the existing plantation is 1092 tonnes, whereas these plantations will sequester 430700 tonnes of CO_2 after the final harvest (60 years). Additionally, it is important to mention here that these plantations will also produce good quality timber wood and contribute to other ecological benefits during the entire silvicultural management.



1.0 Introduction

A global concern of this decade is the rapidly increasing level of carbon dioxide (CO_2) in the atmosphere, which has caused a rise in the atmospheric temperature. It is estimated that anthropogenic emissions of greenhouse gases have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020 (IISD, 2023). There have been several rounds of inter-government discussions to find feasible solutions to reduce emissions and halt climate change. Recently, the countries came together to take action towards achieving the world's collective climate goals as agreed under the Paris Agreement on limiting global warming to below 2°C in the Climate Change Conference (COP 27). However, policies currently in place point to a 2.8°C temperature rise by the end of the century (IPCC, 2022). Some countries and regions in this regard, have prioritized green stimulus expenditures, as part of a 'Green New Deal' (IPCC, 2022). However, measures required to limit warming to 2°C or below can result in large-scale transformation of the land surface.

Conservation, improved management, and restoration of forests and other ecosystems offer the largest share of economic mitigation potential, with reduced deforestation in tropical regions having the highest total mitigation potential. However, ecosystem restoration, reforestation, and afforestation can lead to trade-offs due to competing demands on land (IISD, 2023). The shift in the land use practices, especially agroforestry and forestry sectors, has so far contributed modestly to net mitigation, as past policies have delivered about 0.65 $GtCO_2$ $yr.^{-1}$ of mitigation during 2010–2019 or 1.4% of global gross emissions (IPCC, 2022) and the majority (>80%) of emission reduction resulted from forestry measures. Although the mitigation potential of other land use measures is large from a biophysical and ecological perspective, its feasibility is hampered by a lack of institutional support, trade-offs and weak governance. Despite these impediments to change, land use measures (plantations, agroforestry, forests etc.) for mitigation options are effective and with appropriate support can enable rapid emission reductions in the near future. In addition, forests are recognized as a cost-effective means towards the mitigation of climate change. Consequently, there has been more focus to promote plantations and contribute to the mitigation of climate change.

2.0 Role of Forests/Plantation in Climate Change Mitigation

Forests play a significant role in modulating ecosystems against imbalances such as climate change. Although anthropogenic factors such as emissions, forest fires, deforestation, etc., not only cause to decrease in global forest cover but also reduce the capacity of ecosystems in providing ecosystem services. Bermer & Farely, (2010) concludes that plantations are most likely to contribute to biodiversity when established on degraded lands rather than replacing natural ecosystems. Forest plantations have lead advantages compared to forests in terms of early maturity of trees, more biomass, ease of management, ownership, higher income, etc. Further, the success of the establishment of forests and plantations depends on different stakeholders supported by public, private and non-profit sectors (Holl & Brancalion, 2020). For example, about 2/3rd of high-level commitments for tropical forest restoration involve planting and almost half comprises the establishment of monoculture plantations (Bukoski & Cook-Patton, 2022). The establishment of forest plantations in the context of carbon sequestration has many advantages compared to forests in terms of productivity, rotation and choice. But many stakeholders lack a robust understanding of how much carbon can be captured within monoculture plantations. Growing forest plantations, particularly in the form of block plantations and agroforestry, while emphasizing the rejuvenation of degraded lands is the best option.

Globally forest plantations increased sharply from 167.5 million ha (4.1% of the total forest area) in 1990 to 277.9 million ha (6.9%) in 2015 (Payn et al., 2015), about 20% of the latter are found in the tropical region. In the continuum, the timber supply from natural forests continuously declined, and forest plantations were promoted to meet the demand for wood. For instance, Herault et al., (2010) reported that the mean annual increment (MAI) of natural forests is 1.0 to 5.0 m^3 ha^{-1} $year^{-1}$ and for forest plantations, it ranged from 10.6 to 33.9 m^3 $ha^{-1}year^{-1}$ for *Acacia auriculiformis* elsewhere in Vietnam (Huong et al., 2015), 22.0 to 35.0 m^3 $ha^{-1}year^{-1}$ for acacia and eucalypts plantations in Indonesia (Harwood & Nambiar, 2014). Among the prominent species suitable for plantation, Teak is preferred because of its higher productivity, quality, durability of timber and wider adaptability. Average productivity of Teak plantation is 2.85 m^3 $ha^{-1}year^{-1}$ (Nilambur plantation) in India (vikaspedia, n.d.), 15.3 m^3 $ha^{-1}year^{-1}$ in the Coastal Ecuador (Cañadas-L et al., 2018), 12.5–21.7 m^3 $ha^{-1}year^{-1}$ in Malaysia (Yahya et al., 2011), and 12.0–17.07 $m^3\ ha^{-1} year^{-1}$ in Myanmar (Ladrach, 2009) depending on species, age, and management regimes.

Although forest plantations have shown promising growth and timber yield results, their long-term sustainability remains challenging due to price fluctuation and lack of financial support to encourage good management practices from planting, pruning, thinning, and final harvest (Cuong et al., 2020). So far, there are various possibilities that exist for support and long-term management of forest plantations; however, carbon-based incentives in recent times could be one of the viable options. Recently, raising plantations in the degraded areas is needed to restore the deforested and degraded lands as agreed in SDG 15 and SDG 13 by 2030. Nevertheless, claiming carbon-based incentives in forest plantations requires the full assessment of carbon storage in plantations for the whole management cycle (Ontl et al., 2020). Recent studies on the management of forest plantations focused only on either timber production, paper production or carbon stocks in the standing forests at the final felling (Usuga et al., 2010), but few studies exist that highlight the need for assessing the overall carbon storage due to management for carbon credits. Realizing the benefits and importance of mitigation to climate change through the plantation, corporates are investing their CSR part in the forestry sector.

3.0 Corporate Social Responsibility (CSR) in India

CSR plays an important role in contributing to the overall development of society ensuring businesses to take responsibility for the environment, society and the economy. Globally, CSR has become essential to business operations as companies recognize the need to build trust and strengthen relationships with stakeholders, including employees, customers, investors and communities. Through CSR, companies address global challenges such as poverty, inequality, climate change and environmental degradation, thereby contributing to the development of sustainable communities, promoting human rights and supporting economic growth and social welfare.

India is the first country in the world to make corporate social responsibility through the Companies Act (2013), which mandates companies to meet a specified financial limit to spend 2 percent of their average net profit towards CSR activities. The CSR bill in India has brought about a significant shift in corporate responsibility, with companies investing in areas such as education, healthcare, environment and community development. This has helped to bridge the gap between business and communities ensuring that companies give back to society and promote sustainable development.

To streamline the activities and make the companies liable for the development of society in an economically, socially and environmentally sustainable manner, famously known as the triple bottom line approach of CSR, the Schedule VII of the Companies Act, India has a list of activities that qualify as CSR activities and these activities are in alignment with the Sustainable Development Goals (SDGs) of the UN. The Schedule VII activities emphasize on environmental sustainability, ecological balance, protection of flora and fauna, animal welfare, agroforestry, clean Ganga fund, conservation of natural resources, and maintaining the quality of soil, air and water. These activities are further addressed as environmental CSR aiming to reduce the environmental damages created by businesses through their CSR obligations. There are different activities that a company performs to accomplish its CSR obligations like eradicating extreme hunger and poverty, promoting education, promoting gender equality and empowering women, reducing child mortality, improving maternal health, combating human immunodeficiency virus, acquired, immune deficiency syndrome, malaria and other diseases, ensuring environmental sustainability, employment enhancing vocational skills, social business projects, contribution to the Prime Minister's National Relief Fund or any other fund set up by the Central Government or the State Governments for socio-economic development, and Relief funds for the welfare of the Scheduled Castes, the Scheduled Tribes, Other Backward Classes, minorities and women.

In the financial year 2020-2021, 18012 companies spent around 25714.65 crores in 39 states and union territories in a total of 38790 projects in 14 developmental sectors (National CSR Portal, n.d.). Compared to other equally challenging social issues such as education, poverty, health, sanitation etc., which the companies have prioritised in the past, the environment and related issues somehow failed to gain the desired priority. A look at CSR spending over the last seven years in the Corporate Social Responsibility Data Portal of India's Ministry of Corporate Affairs reveals that the spending under CSR is mostly concentrated towards education, with an average spending of 38% towards this sector, while other spending was in health and sanitation (22%) and rural development (10%), followed by the environment sector (5%) (National CSR Portal, n.d.).

Even under the environment sector, the favoured areas for spending on initiatives such as renewable energy projects, awareness or green initiatives with a meagre allocation for tree planting, rejuvenation and restoration of natural resources like water bodies, forests, grasslands etc. The agroforestry sector, however, received marginal continued funding, thus supporting the objectives of both livelihood and carbon sequestration.

The Indian corporates prefer sectors like healthcare and education rather than environmental sustainability for various reasons but primarily because environmental activities usually have a longer gestation period and difficulty in evaluating the exact impact. The factors make them less advertisable as compared to social activities, which are clearly measurable and can be more visible in terms of the reach of beneficiaries. The corporates face a lack of qualified implementing agencies specialized in restoration and carbon sequestering initiatives, an absence of favourable policy interventions, approvals from various departments and a lack of branding of forest initiatives (Devinsights, n.d.). In the FY 2020-2021, 1332.03 cr. (National CSR Portal, n.d.). was spent by 2696 companies in 35 states in the environment sector, with maximum expenditure on environmental sustainability and least on agroforestry (Table 1).

Table 1 CSR expenditure on different activities under environment in India

Sn.	Sub-sectors	Amount Spent (INR Cr.)
1	Animal Welfare	192.71
2	Conservation Of Natural Resources	90.96
3	Environmental Sustainability	1029.12
4	Agro Forestry	19.24
5	Grand Total (INR Cr.)	1,332.03
Source	https://www.csr.gov.in/content/csr/global/master/home/home.html	

3.1 Role of CSR in Adaptation and Mitigation to Climate Change

Governments around the world are increasingly recognizing the need to bring the focus of CSR towards mitigating climate change. By implementing regulations, policies, reporting requirements and financial incentives, the government has created a framework that incentivizes corporate to reduce their GHGs and implement sustainable practices. Governments have laid mandatory emission reduction targets for corporate, compelling them to reduce greenhouse gas emissions. For example, in many countries, some regulations require companies to report their greenhouse gas emissions and develop strategies to reduce them. This puts pressure on corporate to take concrete actions to mitigate climate change. Governments provide financial incentives, subsidies or tax breaks to corporate that invest in and use renewable energy sources such as solar or wind power (OECD, 2003). These incentives encourage corporate to shift towards cleaner and more sustainable sources of energy, reducing their carbon footprint and contributing to climate change mitigation. Governments also implement market-based mechanisms such as carbon pricing or cap and trade systems, where corporations are required to buy permits or credits for their greenhouse gas emissions (IEA, 2020). In recent years, there has been a growing trend of shifting the focus of CSR from a philanthropic approach to a more strategic and proactive approach towards addressing environmental challenges, including climate change. This includes incorporating environmental sustainability as an integral part of a corporate's business model and operations rather than just a peripheral consideration. Many corporates recognise that sustainable business practices not only help mitigate climate change but also create long-term value for their stakeholders, customers, employees and society at large (IEA, 2020). There has been a successful implementation of CSR projects related to forestry in India. For example, Project Hariyali of Mahindra Group for forest restoration. The project emphasizes planting one million trees annually to address climate change and also support for livelihood opportunities of the local people. A tree-planting initiative born in 2007, the Mahindra Hariyali Initiative (MHI) has not only improved green cover and protected biodiversity but also provides livelihoods to local communities in different parts of the country (Mahindra, 2021). The Group has committed to 1.5 million trees per year until 2026 with the aim to them raise the bar to 5 million trees every year. Since the start of the project till FY2022, the Mahindra Group has planted over 20.65 million trees under Hariyali (1t. Org, n.d.). Another example of CSR Initiatives is ITC model of Sustainable Agroforestry, which encouraged farmers to cultivate maize and chilli as intercrops with eucalyptus and helped to increase the farmers' income, these initiatives have led to 54.58 lakh tonnes of carbon sequestration. Besides, this initiative helped in the restoration of groundwater and the enhancement of farmers' income (ITC, n.d.).

Such activities are often complimentary for the government and private companies. Collaboration between the government and the private sector can effectively improve national CSR standards within businesses. By laying down minimum standards and encouraging companies to reach above and beyond this threshold, government involvement will ensure that social objectives are followed through and that voluntary social CSR initiatives are carried out to an appropriate standard. Studies have also shown that CSR creates social values and improves social welfare, which constitutes the main goals of government policy (Bichta, 2003). That is the main reason behind CSR, often referred to as the 'triple bottom line principle', implying business should serve both economic and social and environmental ends. The idea can effectively improve CSR practices within the business if the cooperation between public and private entities is strengthened. To explore new avenues and strengthen cooperation in the sector, MPRVVN Limited and Havells India Limited jointly started the plantation of Teak in Madhya Pradesh.

4.0 The Current Project

Havells India Limited is a leading Fast Moving Electrical Goods (FMEG) Company and a major power distribution equipment manufacturer with a strong global presence. The company supports a number of initiatives/activities under the CSR. The CSR efforts of Havells revolve around eight strong pillars of health and nutrition, education, skill development, sanitation, healthcare, environment, heritage conservation and other humanitarian causes, which are also in compliance with achieving the United Nations Sustainable Development Goals. In the field of environment, the Havells continuously made an effort to contribute towards sustainable improvement of the forest ecosystem. The efforts and investment in afforestation clearly show Havell's commitment to net zero carbon through carbon sequestration by raising forest plantations.

Recently, the company has entered into an MoU with Madhya Pradesh Rajya Van Vikas Nigam (MPRVVN), wherein Van Vikas Nigam is committed to planting 4 lakhs saplings on an annual basis, starting from 2018 to 2027. Under this MoU, MPRVVN has planted 1.725 million Teak seedlings on 690 hectares of degraded forest land in Raisen, Sagar and Vidisha districts of Madhya Pradesh between 2018 and 2022. The plantation drive started in 2018 with 50 ha in compartment no 427 of the Sehore Division. The Nigam has carried out silviculture practices such as tending and cultural activities in the plantations. The details of the plantation from 2018 to 2022 with Havells support are given in Table 2.

Table 2 Details of the plantations carried out by MP Rajya Van Vikas Nigam

Sn.	Compartment No	Area (ha)	No of plants (in lakh)	Total expenditure (INR)	Per ha cost	Range	Division	Year of plantation
1	427	50	125000	11000000	220000	Ladkui	Sehore	2018
2	P-312	60	150000	11004314	183405	Gyaraspur	Vidisha	2019
3	P-322	40	100000	7404312	185108	South Lateri	Vidisha	2019
4	P-333	60	150000	10917116	181952	North Lateri	Vidisha	2019
5	R-233	50	125000	10059221	201184	Samshabad	Vidisha	2020
6	R-234	55	137500	11018273	200332	Samshabad	Vidisha	2020
7	R-239A	55	137500	10918701	198522	Samshabad	Vidisha	2020
8	232-A	45	112500	9180428	204010	Samshabad	Vidisha	2021
9	548	115	287500	22783092	198114	Samshabad	Sagar	2021
10	R-232V	115	287500	22766652	198375	Samshabad	Vidisha	2022
11	548V	45	112500	9145029	204231	Samshabad	Sagar	2022

5.0 Teak Plantations/Forests in India

Teak (*Tectona grandis*) is an economically important tree belonging to the family Lamiaceae, and indigenous to South and Southeast Asia, mainly Bangladesh, India, Indonesia, Malaysia, Myanmar, Thailand and Sri Lanka. In India, Teak grows in dry areas of Tamil Nadu, Rajasthan, Madhya Pradesh, Andhra Pradesh and Maharashtra, with a ranging maximum temperature up to 48°C and a minimum of about 2°C in the dry zone of Central India. While in the moist parts of Southern India (west coast), the maximum and minimum temperatures of Teak distribution ranges from 43°C to 13°C, respectively. The growth of Teak varies with local conditions and management practices; typically, Teak grows well in average rainfall of 1,250–1,650 mm with a 3–5-month dry season and soil pH ranging from 6.5 to 7.5. Almost 29% of the total forest in India is Teak dominant forest.

Teak forests are widely distributed in Madhya Pradesh, and the quality of the Teak is best compared to other Teak-dominated states. Because of the geographical positioning of the state, the growth attributes in Teak are better. Madhya Pradesh is considered the best site for the growth of Teak. The state comprises about 18,332 sq. km of Teak forests, which accounts for about 19.36% of the total forest cover. The maximum Teak distribution is in Narmadapuram, Betul, Chhindwara, Seoni and Mandla districts.

5.1 Management Practices of Teak

The growth and success of any forest plantation are attributed to risk factors such as pests, fire, landslides, etc., capacity for management (irrigation, fertilizer application, thinning, pruning, coppicing, etc.) and sustainability. However, the level of risk faced by plantation forests depends on the degree of local factors, initial planning, such as plant spacing, season and depth of planting, accounts for the survival of plants. The intensity level decides the timber quality and yield in Teak. For instance, Kumi et al., (2021) compared biomass, carbon stock accumulation and soil nutrient levels in an intensively managed (IMP) and less intensively managed (LIMP) Teak plantation in Ghana. They found that The IMP significantly accumulated biomass (22.52 Mg/ha) and carbon stocks (50.56 Mg/ha) than the LIMP (biomass 14.44 and carbon 6.66 Mg/ha); however, LIMP had a higher number of forked trees than the IMP implying intensity of management significantly influence the higher survival rate, taller trees, larger basal area, resulting in higher biomass and carbon stocks observed in the intensively managed plantation. Similarly, Koppad & Roa, (2013) studied Teak plantations raised with high input management practices, viz., application of fertilizers (organic and chemical), irrigation, weed management and intercultural operations in two-year-old plantations. Plantations raised without any management practices were selected as poorly managed plantations. Observations were recorded in five years and ten-year-old plantations, and results indicated that about 0.976 and 2.579 tons of excess carbon were sequestered per hectare per year in better-managed plantations over conventional grown (poorly managed) five and ten-year-old Teak plantations, respectively. The results indicated that high input management practices followed at initial years (2-3years) had increased the carbon sequestration in five and ten-year-old Teak plantations.

Generally, the Teak seedlings are widely adapted with a spacing of 2x2 m, 3x3 m and 4x4 m initial spacing. As the plantation establishes, the spacing is gradually increased through thinning depending on the site and growth conditions. Various factors affect the growth and quality of the plantation, particularly the site quality, seed source and management practices. Site quality has a direct effect on the establishment and growth of the plantation. Therefore, appropriate and timely silviculture management must be carried out to improve both the growth rate and quality.

Thinning is an important silvicultural treatment carried out in plantations in different intensities to alter stand structure and improve volume growth. The practice has an advantage such as removing dead and diseased trees help in improving the existing trees, reducing the competition, providing intermediate yield, etc. Biomass accumulation in the tree increases with increasing thinning practices up to certain extent age of the trees. Accordingly, the proposed silvicultural practice and thinning guidelines of the Havells' plantation by MPRVVN are summarized in table 3.

Table 3 Details of the management practices for the plantations as per the guideline of MPRVVN

Sn.	Compartment No	Area (ha)	Year of plantation	First thinning (11th year)	Second thinning (16th year)	Third thinning (21st year)	Fourth thinning (26th year)	Fifth Thinning (31st year)	Sixth Thinning (36th year)	Seventh Thinning (41st year)	Eighth Thinning (45th year)	Felling (60th year)
1	427	50	2018	2029	2034	2039	2044	2049	2054	2059	2064	2078
2	P-312	60	2019	2030	2035	2040	2045	2050	2055	2060	2065	2079
3	P-322	40	2019	2030	2035	2040	2045	2050	2055	2060	2065	2079
4	P-333	60	2019	2030	2035	2040	2045	2050	2055	2060	2065	2079
5	R-233	50	2020	2031	2036	2041	2046	2051	2056	2061	2066	2080
6	R-234	55	2020	2031	2036	2041	2046	2051	2056	2061	2066	2080
7	R-239A	55	2020	2031	2036	2041	2046	2051	2056	2061	2066	2080
8	232-A	45	2021	2032	2037	2042	2047	2052	2057	2062	2067	2081
9	548	115	2021	2032	2037	2042	2047	2052	2057	2062	2067	2081
10	R-232V	115	2022	2033	2038	2043	2048	2053	2058	2063	2068	2082
11	548V	45	2022	2033	2038	2043	2048	2053	2058	2063	2068	2082
No of tree per ha after the management (for site quality III/IV)				1322	882	670	544	457	390	346	319	319
No of tree per ha after the management (for site quality IV)				1364	1124	857	687	603	534	479	440	440

5.2 Biomass and Carbon Sequestration in Teak

The Teak has the potential for biomass accumulation over the periods, which varies with age, site condition and management practices. Many researchers in India already revealed biomass partitioning with age and site condition. For instance, Karmacharya & Singh, (1992) analyzed the biomass and carbon accumulation in Teak in an age series of Teak plantations (4, 14 and 30 years old), raised in a dry tropical region in northern India. The standing crop biomass and aboveground net production ranged from 25.7 to 76.9 tonnes ha^{-1}. The proportion of woody biomass was 56% of the total at 4 years, increasing to 91% of the total by 30 years. very high aboveground net production was obtained at 4 years (25.6 tonnes ha^{-1} $year^{-1}$), but net production decreased with age (14 and 12.9 tonnes ha^{-1} $year^{-1}$ at 14 and 30 years).

The biomass production and accumulation of Teak also varies from forests to pure plantations. A detailed assessment of forest type wise biomass and carbon was done by (Salunkhe & Khare, 2016) in the Madhya Pradesh forests. The biomass stocks of four different types of forests, viz., mixed non-Teak Forest (MNTF), dry mixed non-Teak Forest (DMNTF), Teak-dominated Forest (TDF) and dry Teak Forest (DTF), was estimated at twelve different sites in Damoh, Katni, Raisen, and Sagar districts. Indicator species for dry conditions considered in the study were *Acacia catechu, A. nilotica, Aegle marmelos* and *Ziziphus sp*. Biomass and carbon were estimated by non-destructive method and tree allometric equations. Measurements for basal area and tree height were converted into a volume using regional species-specific gravity. The study quoted that the mean basal area of forest trees ranged from 4.33 to 9.0 m^2 ha^{-1}, the maximum in MNTF. The MNTF contributed higher above-ground biomass and carbon stock. Significant positive correlations were observed between the basal area and the aboveground biomass. The carbon stock of four typical dry deciduous forests was estimated at 25-54 Mg/ha (MNTF), 13-42 Mg/ha (DMNTF), 33-53 Mg/ha (TDF) and 16-24 Mg/ha (DTF). The total biomass of Teak in Dehradun was 147.50 tonnes $ha^{-1,}$ with above-ground biomass (AGB) of 121.88 tonnes ha^{-1} and below-ground biomass (BGB) of 25.62 tonnes ha^{-1} (Giri et al., 2014).

Teakwood is renowned for its strength, resistance to decay and insect attack, making it a highly sought-after timber in the global market. A compilation of different studies related to the assessment of biomass/carbon for Teak in Asia is provided in Table 4.

Table 4 Biomass accumulation pattern in Teak

Region	Vegetation type	Age (years)	Density (ha)/spacing	Biomass accumulation (Mg/ha)	Carbon sequestration (kg per tree)	Carbon sequestration (Mg/ha)	Reference
Karnataka	Plantations	10, 15 and 20	–	–	149, 231,702	70.27, 108, 330	Reddy et al. (2014)
Uttarakhand	Plantation	28, 38, 48	–	458,477,858	–	229,238,429	Nirala et al. (2018)
Kerala	Plantation	10, 15, 20, 30, and 40	1739, 318, 126, 103, 40 and 19 trees removed/ha	67, 154, 223, 237, 408, 752, 1052 kg/tree	29, 67.01, 103, 179, 332, 463 kg/tree	50.43, 21.30, 12.97, 18.43, 13.28, 8.79	Sreejesh et al. (2013)
Odisha	Plantation	32	4m× 4m	64.05 to 223.72m3/ha	12.4 to 489.6	204 to 306	Behera, and Mohapatra (2015)
Madhya Pradesh	Forest	–	415	105.46	120.69	50.09	Chave et al. (2005)
Uttarakhand	Forest	1 to 30	–	–	3.42 to 155	1.61 to 73.23	Jha (2015)
India	Forest	4	3490	-	3.61	12.61	Karmacharya, and Singh (1992)
Indonesia	Plantation	1 to 14	3x3 m	5.8 to 115.0	2.41	2.68 to 54.01	(Wirabuana et al. 2022)
Thailand	Plantation	17, 24, 31, 35	625, 312, 218, 156	–	30.56, 263.14, 334.86, 291	19.1, 82.1, 73.0, 45.4	Chayaporn et al. (2021)

6.0 Objectives:

Afforestation and plantation are primarily the mandates of the respective forest departments of the states in India. However, carbon sequestration by forests/plantation has attracted much interest as a mitigation approach to climate change, as it has been considered a relatively inexpensive means of addressing climate change immediately. This has also attracted many corporates to contribute to mitigating climate change through plantation as part of their CSR. In this regard, the current study is conceived with the following objectives:

- **To assess the survival rate of Havells' plantation done by MPRVVN limited.**
- **To predict the total carbon sequestration potential of the Havells' plantations.**
- **To estimate the carbon sequestration of the existing teak plantation.**

7.0 Materials and Methods

7.1 Study area

The study was conducted in Teak plantations of different age groups in eight compartments viz., P-312 and P-322 in South Lateri, P-333 and R-239A in North Lateri, R-233, R-234, 232-A in Shamshabad of Vidisha Forest Division and 548 in Gyraspur range of north Sagar Forest division. Situated in the central part of Madhya Pradesh, Vidisha district lies between the North Latitudes 22°20' and 24°22' and East Longitudes 77°16' and 78°18' with an average elevation of 511 meters. The district is bounded by Raisen district in the South, Guna district in the North, and Sagar district in the East. The climate of Vidisha district is characterized by a hot summer and general dryness except during the southwest monsoon season. The mean monthly temperature ranges between 11°C and 41°C, and the average annual rainfall is 1135.5mm. The district of Sagar lies in the north central region of Madhya Pradesh. It is situated between 23°10' and 24° 27' north latitude and between 78° 4' and 79° 21' east longitude, the district has a truly central location in the country. The forest types of both districts are categorized under group 5A/(1b) as 'tropical dry deciduous forest' (Champion & Seth, 1968). Figure 1 below depicts the plantation sites in both districts.

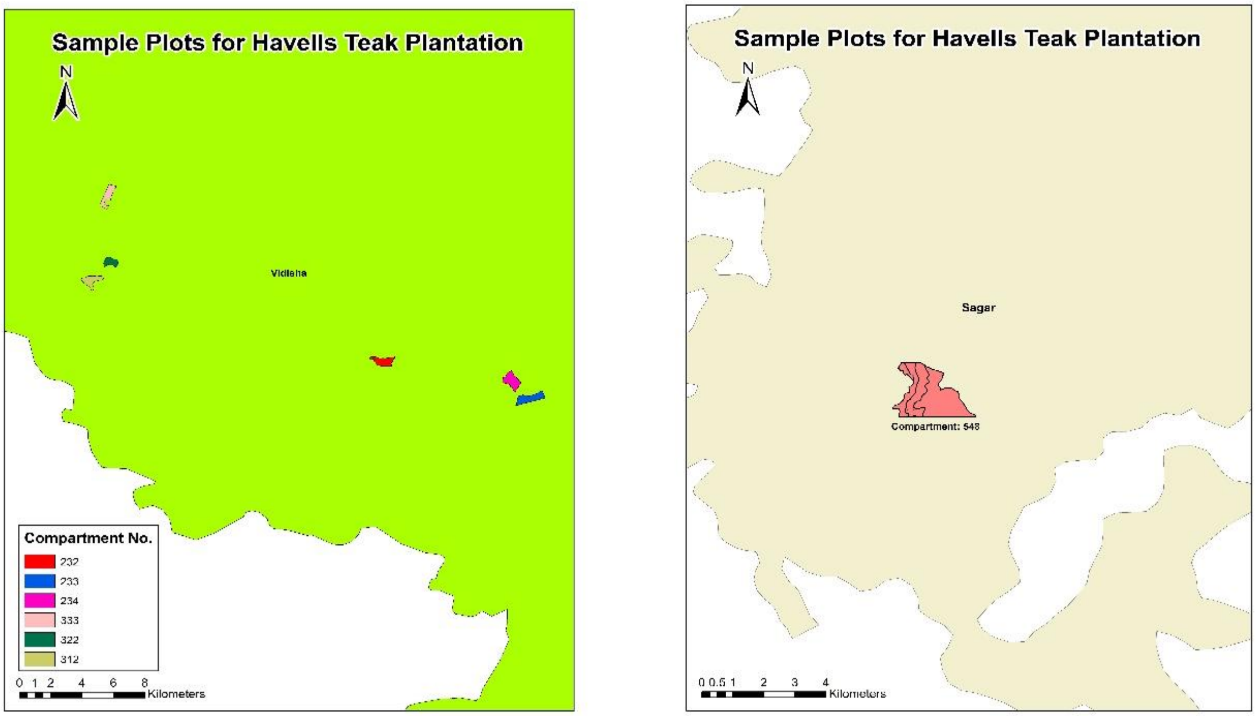


Figure 1 Compartments of Teak plantations in Vidisha and Sagar districts

7.2 Proposed Methodology

7.2.1 Sampling Strategy and Data Collection

Havells India Pvt. Ltd has supported plantation in 690 ha activities from 2018 to 2022 in 11 compartments (Table-2). For the current assessment, the plantations of 480 ha done between 2019 and 2021 were considered. A detailed discussion was undertaken with the officials of the Forest Department about the locations of the plantation, and a reconnaissance survey was carried out on 28th January 2023 across compartments for adopting suitable methods and sampling techniques as per the site conditions. Detailed information was collected, such as site maps of the plantations and age, thinning operations, protection measures etc.

The stratified random sampling method was used for field measurement. Quadrats of 0. 1 ha (31.62 m × 31.62 m) were laid in all compartments representing different years of plantation. A total of 192 plots were laid in all the plantation sites covering 19.2 ha sampling area (total area 480 ha), covering 4% of the total plantations in each compartment. Additional quadrats (2 each) were laid in nearby plantations of 10 years (North Sagar division) and 15 years' age (Vidisha division) to understand the growth patterns of plantations. All seedlings/saplings found in the quadrat were enumerated, and their height and collar girth (6 cm above the soil surface) were recorded using measuring tape. Similarly, for trees, the girth was measured at breast height (1.37 m above the ground level). The above-collected data was analyzed to find the survival rate, average diameter at breast height (DBH), average collar girth and average height across various compartments. The detailed enumeration was carried out from 15 February to 28 February 2023 across the different aged plantations, viz., 2019, 2020, and 2021. A non-destructive technique was adapted for the estimation of biomass and carbon of the varying aged plantation.

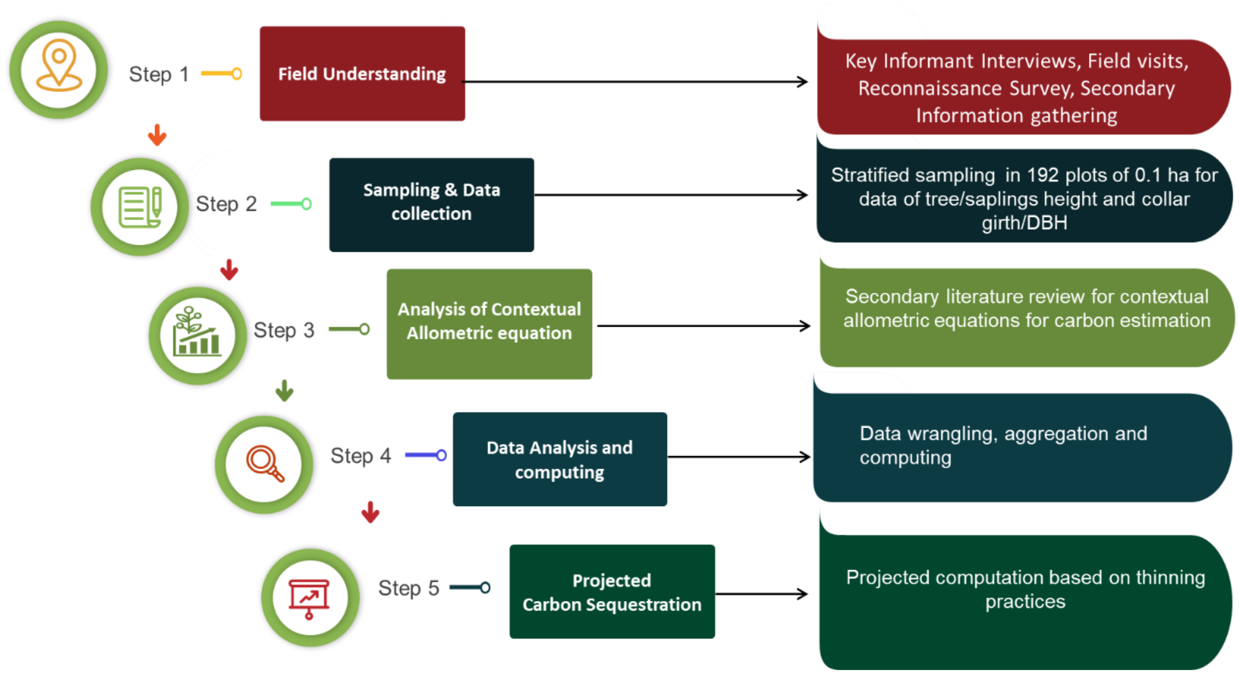


Figure 2 Methodology flow diagram for the assessment of carbon/biomass for the Havells plantation

7.2.2 Data Analysis and Carbon Calculation

The data collected from the field was analyzed using descriptive statistics to find the average height, DBH, collar girth etc. by compartments/age/division. Post descriptive analysis, it was realized that the growth patterns of each division were distinct and corroborated to different site qualities, as per the MPRVVN's field manual. As the duration of the study was three months, the only feasible option to calculate biomass/carbon was through using non-destructive method. This entailed us to choose a suitable equation from existing studies/reports, based on our site qualities.

7.2.3 Selection of Suitable Allometric Equations

There are two types of methodologies for the estimation of biomass/carbon: destructive and non-destructive. In the estimation of biomass, error mostly occurs during the selection of the allometric equations (Fonseca et al., 2012). Generally, a common volumetric/allometric equation is applied for biomass estimation over a large area (Houghton, 2003) where the biomass might differ due to variations in topography, environmental conditions, stand age, species composition and natural and anthropogenic disturbances. To reduce uncertainty in biomass estimation, site-specific allometric equations could be used (Wang et al. 1995, Brown 1997). Tree species may differ in their architecture, wood density or wood-specific gravity; therefore, species-specific allometric equations are generally preferred for reducing uncertainty due to species (Ketterings et al. 2001). Thus, choosing a suitable allometric equation for estimating biomass/carbon is important. Some of the equations are based on DBH alone, whereas some are based on both DBH and height for calculating biomass. Biomass estimation errors could also be observed if the equation used for a particular diameter range is applied to another diameter range. A list of different equations used for calculating the biomass of Teak in different parts of India is listed in Table 5.

Table 5 List of volume/biomass equations to estimate the AGB of Teak forest/plantation

Sl. No.	Equations	Location	Age	Source
1	V = (0.043460.26352*SQRT(D)+8.79334) *(D*D)	MP	Natural	(Salunkhe and Khare, 2016)
2	$V = (0.1657 - 1.1235D + 8.0855D^2)$	MP	Natural	(Raha et al., 2020)
3	$V = 0.0884-(1.46936*D) +11.98979*(D^2) +1.97056*(D^3)$	UP	Plantation	(CDM, 2015)
4	AGB Tree = $(0.4*(GBH/3.142)^2)$ *H*wood density	Gujarat	Natural	(Pandya et al., 2013)
5	V = (-0.003673-0.379175*D) +6.368282*D*D	MP	Natural	(FSI, 2021)
6	AGB tree (Y) = $0.0758*(D)^{2.6135}$)	UP	10-30	(Negi, 1995)
7	$V=(0.1657-1.1235D+8.0855D^2)$	UK	28	(Giri et al., 2014)
10	$AGB=0.4989D^2–0.202D-21.971$, $BGB=0.1257D^2–1.8573D+9.2119$, $TB=0.6246D^2–2.0593D-12.759$	UK	1-30	(Jha, 2015)
11	V = (-0.003673-0.379175*D)+6.368282*D*D	MP	Natural	(ICFRE, 2021)
	*V=Volume, D= Diameter at the Breast Height, AGB= Above ground Biomass, H= Height of the tree, CS= Carbon Stock, VOB = Volume of Bole, BGB= Below Ground Biomass, TB= Total Biomass			

In order to minimize such errors, different equations for different DBH classes (ranging from < 3.2cm to > 31.8cm in 10 D classes), as proposed by Pati et al., (2022) and Chaturvedi & Raghuvanshi, (2015), were used in our study. These equations for different DBH classes were developed on measured biomass of Teak in 11 diameter classes occurring in tropical dry forests of India by harvest method. The other variables used in these equations were wood density and height. However, we observed some discrepancies for some intermediate DBH classes, and therefore we have used an equation that gave us a closer estimate as per the ecological principles. The details of the equation used in the current study for different diameter of trees under Havells' plantation is summarized in Table 6.

Table 6 Different allometric equations selected for calculating biomass/carbon

Sn	D class (cm)	Allometric equations
1	<3.2	lnAGB=1.868+.825(InD)+1.281(InH)-1.217(In wood density) (Pati et al., 2022)
2	≥3.2-<6.4	InY=5.618+.413InX (Chaturvedi & Raghuvanshi, 2015)
3	≥6.4-<9.6	lnY=5.166+.449lnX (Chaturvedi & Raghuvanshi, 2015)
4	≥9.6-<12.7	lnY=1.456+.784lnX (Chaturvedi & Raghuvanshi, 2015)
5	≥12.7-<15.9	$\ln Y = 11.09+0.503e^{-e-(\ln X-12.42/0.047)}$ (Chaturvedi & Raghuvanshi, 2015)
6	≥15.9-<19.1	$\ln Y = 11.80+.141e^{-e-(\ln X-13.01/.011)}$ (Chaturvedi & Raghuvanshi, 2015)
7	≥19.1-<22.3	$\ln Y = 11.98+.456e^{-e-(\ln X-13.40/.093)}$ (Chaturvedi & Raghuvanshi, 2015)
8	≥22.3-<25.5	$\ln Y = 12.72+.455e^{-e-(\ln X-14.15/.039)}$ (Chaturvedi & Raghuvanshi, 2015)
9	≥25.5-<28.7	lnY= -9.096+ 1.553lnX (Chaturvedi & Raghuvanshi, 2015)
10	≥28.7-<31.8	lnY= -3.314+1.144lnX (Chaturvedi & Raghuvanshi, 2015)
11	≥31.8	lnY=4.998+.579lnX (Chaturvedi & Raghuvanshi, 2015)

7.2.4 Methodology for Carbon Sequestration Potential of Plantations

The growth table of teak is an important data source for the enumeration of future carbon sequestration. The field manual was referred for the growth table of teak for the two site qualities of Havells plantations. The Forest department carries out manual thinning operations to facilitate the growth of healthy trees and the accumulation of wood biomass. This is done at various intervals like 11,16, 21, 26, 31, 36, 41, and 45 until the final felling at the 60th year (Table-3). The felling regime is also specific to site quality as prescribed in the forest field manual. The rate of carbon sequestration at different growth stages is different. The Biomass of trees removed from the site through felling at each stage, including the final felling stage, was only considered for estimating carbon sequestration, similar to the methodology used by (Sreejesh et al. 2013). The cumulative carbon sequestered by these trees was calculated over time to estimate the total carbon sequestered at various ages of plantation and thinning intensities. The growth tables were referred to for likely Height and DBH at various ages linked to thinning practices, and subsequently, different allometric equations prescribed by Chaturvedi and Raghuvanshi (2015) for different DBH were used for calculating biomass/carbon. Further, a representative field data collection was done on 2 plots, each of 0.1 ha, in 10- and 16-year-old plantations in similar regions to check growth patterns of teak trees to calculate site quality-specific biomass/carbon accumulation over time. It is important to mention that the projected biomass and carbon calculation of trees at a maturity of 60 years for final harvest is done on the average diameter and height of the plantation that existed in the plantation site. Whereas the calculation of biomass/carbon of trees at different ages linked to the thinning practice is based on DBH, and height is given in the field manual of MPRVVN (Table 7). The plantations of Havells under the current evaluation are in two site qualities, i.e., Site quality III/IV has 265 ha (Sagar=115 ha & Vidisha=150 ha), and Site quality IV has 215 ha (Vidisha). Table 7 gives details of a total standing tree after systematic thinning as per the prescription of the forest department.

Table 7 Reference table of DBH and height at different ages as per the field manual of MPRVVN

Age (yrs)	Average Girth Site III/IV (cm)	Average Height Site III/IV (m)	Average Girth Site IV (cm)	Average Height Site IV (m)	Total no of trees after thinning in Site quality III/IV (in 265 ha)	Total no of trees after thinning in Site quality IV (in 215 ha)
11	27	7	24	6	352980	293260
16	34	9	30	7	233730	241660
21	40	11	34	9	177550	184255
26	45	13	38	10	144160	147705
31	50	14	41	11	121105	129645
36	55	15	45	12	103350	114810
41	60	16	48	13	91690	102985
45	64	17	50	14	84535	94600

8.0 Results and Discussion

8.1 Field Survey, Sample Plots, Girth, Height, Sampling Intensity and Survival

Madhya Pradesh Rajya Van Vikas Nigam (MPRVVN), with financial help from Havells India Limited, has planted 1.725 million teak seedlings on 690 hectares of degraded forest land in Vidisha and Sagar districts of Madhya Pradesh. Indian Institute of Forest Management (IIFM), Bhopal, has surveyed and analyzed the plantation done between 2019 and 2021 in the said districts. However, on the basis of field observations & measurements of DBH and the height of existing plantations of different ages revealed that the site quality of 215 ha in the Vidisha division falls in the category of IV, and 150 ha plantation of Vidisha and 115 ha plantation of Sagar division is site quality III/IV. The field survey was conducted in the month of February 2023. The survival rate of the plantation was above 90% in all the compartments across different sites. Table 8 below provides the details of sampling intensity and the survival rate of the plantations.

Table 8 Range and beat-wise details of the field survey of the plantation sites

Compartment Number	Year of Plantation	Average Collar Diameter(cm)	Average Height (m)	Net area (ha)	Sampling intensity (ha)	Survival %
312	**2019**	**3.30**	**0.96**	**60**	**2.4**	**90.15**
322	**2019**	**4.03**	**1.41**	**40**	**1.6**	**90.50**
333	**2019**	**3.05**	**0.93**	**60**	**2.4**	**96.31**
239A	**2020**	**3.89**	**1.49**	**55**	**2.2**	**93.69**
548IV	**2021**	**2.56**	**0.96**	**115**	**4.6**	**98.52**
R232A	**2021**	**2.38**	**0.82**	**45**	**1.8**	**95.63**
R233	**2020**	**2.81**	**0.98**	**50**	**2**	**97.24**
R234	**2020**	**3.45**	**1.25**	**55**	**2.2**	**98.14**

8.2 Estimated Total Carbon Sequestered by the Havells Plantation in 60 years (site quality III/IV, Sagar/Vidisha)

In Sagar/Vidisha division (site quality III/IV), a total of 319 Teak trees/ha will be left after 45 years for the final harvest after sixty years. In the current project, 265 hectares out of 480 hectares are in Sagar and Vidisha divisions, and their total number in different age classes is calculated as per site quality III/IV (Table 7). For this site quality, the per hectare above-ground carbon (AGC) is estimated at 178.43 tonnes/ha, while the below-ground carbon (BGC) is estimated at 59.47 tonnes/ha. The total carbon stock (AGC +BGC) for 265 hectares' plantation for a 60-year rotation is estimated as 63046 tonnes, and the total CO_2 sequestered is 231378 tonnes (Figure 3). Table-9 below depicts the age-wise carbon sequestered for the site quality III/IV.

Table 9 Details of carbon accumulation and CO_2 sequestration in different years of Saga/ Vidisha division (265 ha, site quality III/IV)

Thinning Regimes (at year)	**Tree removed**	**Carbon/ha (tonnes)**	**Total carbon (tonnes)**	**Total CO_2 sequestered (tonnes)**
11	1161	1.54	407	1493
16	450	0.82	217	797
21	212	13.49	3576	13123
26	126	8.02	2125	7799
31	87	7.84	2078	7627
36	67	6.04	1600	5874
41	44	6.51	1724	6328
45	27	3.99	1058	3883
60	319	189.66	50261	184454
	Total	237.909	63046	231378

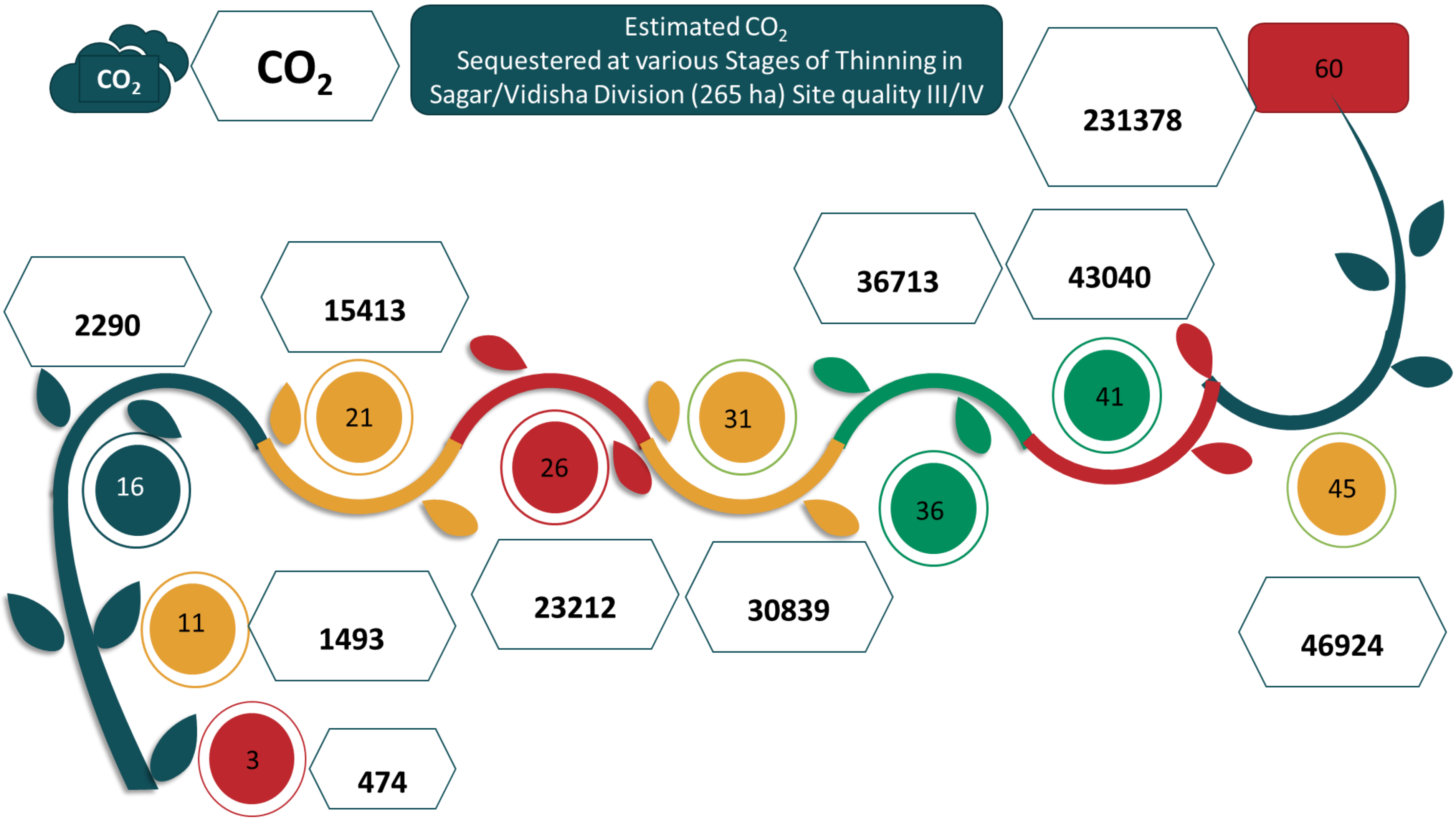


Figure 3 Details of Cumulative CO_2 (in tonnes) sequestration for Sagar/Vidisha division (265ha)

8.3 Estimated Total Carbon Sequestered by the Havells Plantation in 60 years (site quality IV, Vidisha)

In the Vidisha division, 440 mature Teak trees/ha will be left for the final harvest in the rotation period of sixty years. In the current project, 215 out of 480 hectares fall in this site quality as per their recorded growth parameters in the field. For this site quality, the per hectare above-ground carbon (AGC) is estimated at 189.46 tonnes, while the below-ground carbon (BGC) is estimated at 63.15 tonnes. The total carbon stock (AGC +BGC) for 215 hectares for a 60-year rotation is estimated at 54311 tonnes, and the total CO_2 sequestered is 199320 tonnes for the 60-year rotation period for the Havells plantation (Figure 4). Table-10 below depicts the age-wise carbon sequestered for the site quality IV.

Table 10 Details of carbon accumulation and CO_2 sequestration in different years of Vidisha division (215 ha)

Thinning Regimes (at year)	Tree removed	Per ha carbon sequestration (tonnes)	Total carbon sequestration tonnes (215 ha)	Total CO_2 equivalent (in tonnes)
11	1041	1.38	296	1086
16	240	0.44	94	345
21	267	0.62	132	486
26	170	0.47	101	370
31	84	5.35	1149	4219
36	69	4.39	944	3465
41	55	3.50	753	2762
45	39	2.48	534	1959
60	440	233.99	50308	184628
	Total	252.608	54311	199320

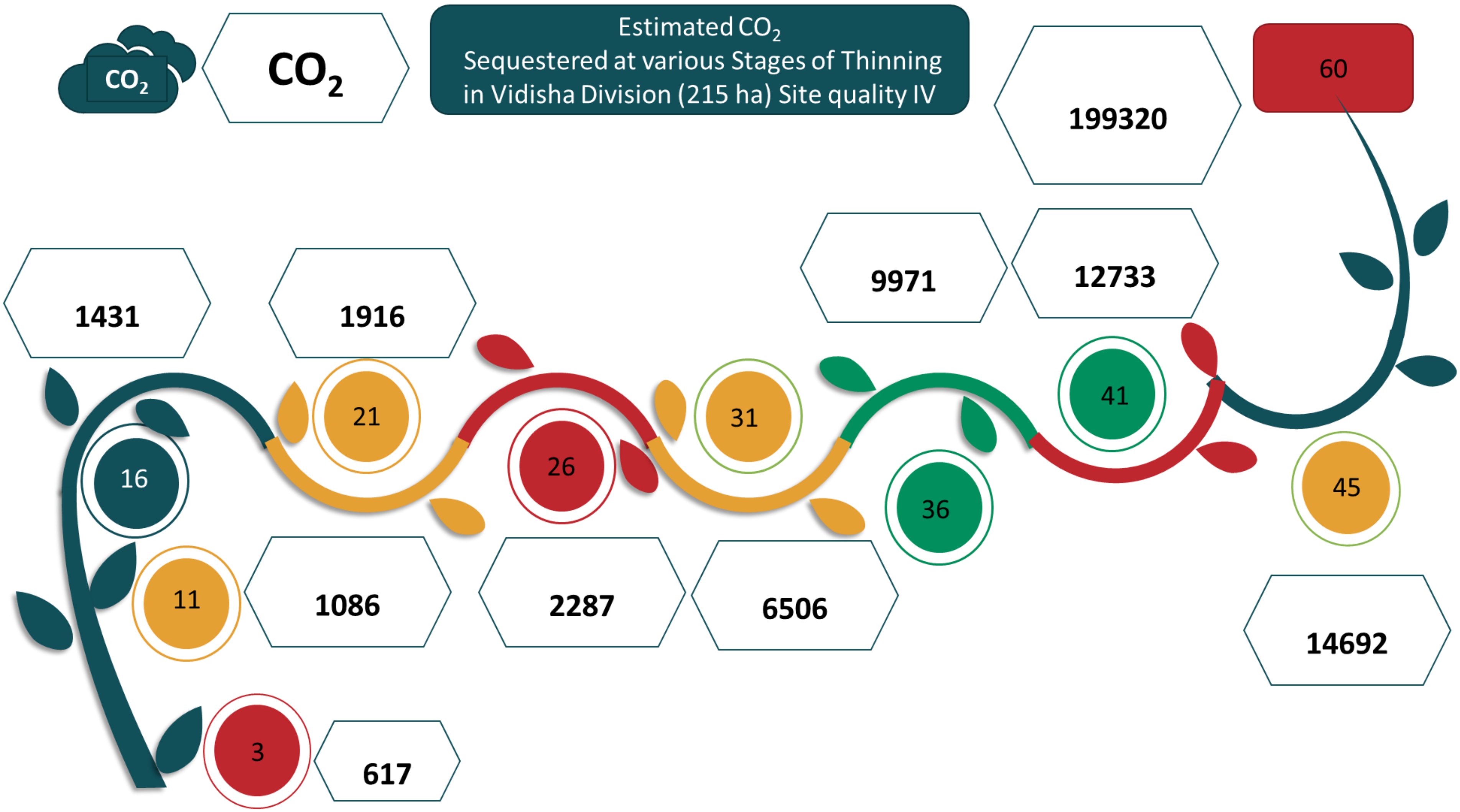


Figure 4 Details of cumulative CO_2 sequestered (tonnes) for Vidisha division (215 ha)

8.4 Total Carbon Sequestration and CO_2 equivalents of the Havells' plantation (480 ha)

The total carbon and CO_2 sequestered at various stages are represented in figure 5. The total CO_2 sequestered are represented in hexagons, and the amount of carbon sequestered is depicted graphically in cylinders. It is estimated that the Havells' plantation in 480 ha will sequester 117357 tonnes of carbon and 430700 tonnes of CO_2, respectively.

Since teak is an important hardwood species grown worldwide, many forest scientists and researchers have researched the productivity of teak forests and plantations. These studies have reported the carbon sequestration potential in natural as well as plantation sites of Teak in many parts of the world. Reddy et al. (2014) studied the carbon sequestration potential of 10-, 15- and 20-year-old Teak plantations in Karnataka and reported its productivity at 70.27, 108, 330 tonnes per hectare. Nirala et al., (2018) in Uttarakhand reported the carbon sequestration potential of 28, 38, 48 years old Teak plantations at 229,238 and 429 tonnes per hectare. Chave et al., (2005) studied the carbon sequestration potential in the Teak Forest of Madhya Pradesh and reported the sequestration potential of 50 tonnes per hectare. Behera & Mohapatra, (2015) in Odisha estimated the carbon sequestration of a 32-year-old Teak plantation between 204 to 306 tonnes per hectare. Jha, (2015) concludes that the carbon sequestration of Teak- Forest in Uttarakhand in the age group of 1- 30 years' ranges from 1.61 to 73.23 tonnes per hectare. These literature reviews suggest that the carbon sequestration potential of Teak in well-managed plantations is higher as compared to the natural forest. In our study as well, the carbon sequestration potential of Teak-Plantation at the 60^{th} year ranges from 237.91- 252.61 tonnes per hectare in different site quality, which is in sync with the reported numbers of the various studies (table- 4) in India and outside India.

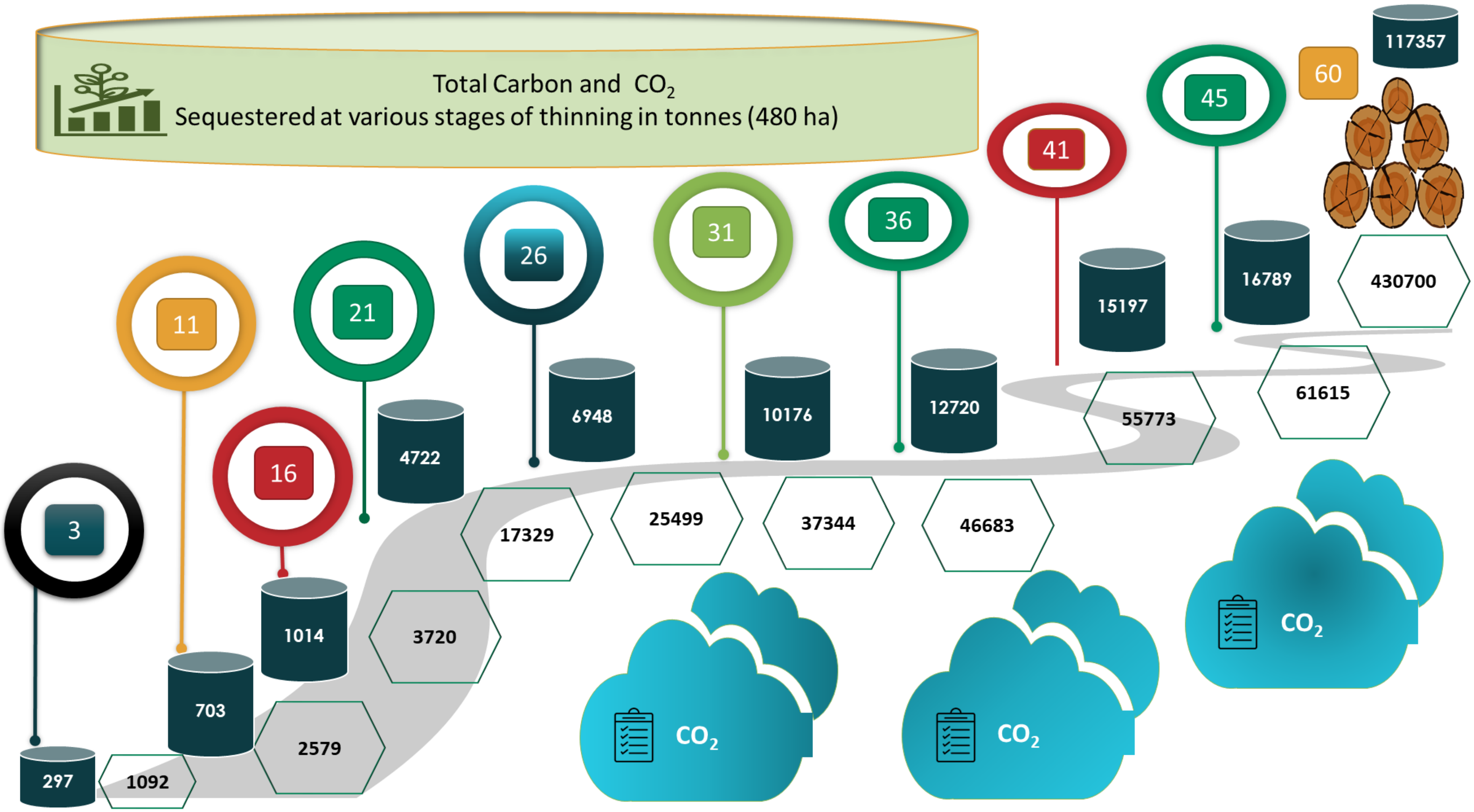


Figure 5 Total carbon and CO_2 sequestered (tonnes) for the entire Havells Plantations over full rotation period of 60 years

8.0 Total Carbon Sequestration of the Young Havells Plantations in 2023

Based on various equations in table number 5, the total carbon in the existing plantations of three different years' ranges between 27 tonnes to 297 tonnes (Table- 11). The carbon di-oxide equivalent thus ranges between 97 to 1091 tonnes. The large variation in the carbon stock hence suggests that it is quite a challenging process to estimate the carbon stock in the young-age plantations on the basis of studies that are conducted elsewhere. Based on the field observation, we can infer that the value of 1092 tonnes of CO2 equivalent is the most appropriate value, representing the total CO_2 sequestered by the existing plantation of 480 ha. This has been derived from the combined equation of Pati et al., (2022) and Chaturvedi and Raghuvanshi (2015), who have developed specific equations for different girths and height of the Teak.

Table 11 Total carbon and CO_2 in tonnes by using various equations from young teak plantations

Site Quality	(Pandya et al., 2013)	Combined Pati & Chaturvadi and Raghubanshi	(Pati et al., 2015)	(CDM, 2015)	(Raha et al., 2020)	Carbon (Salunkhe & Khare, 2016)	(ICFRE, 2021)
III/IV (carbon)	96.32	129.21	109.41	34.97	14.85	16.03	11.98
IV (Carbon)	122.61	168.22	122.46	44.86	18.07	19.28	14.52
Total (Carbon)	**218.92**	**297.43**	**231.88**	**79.84**	**32.92**	**35.30**	**26.50**
III/IV (CO_2)	353.48	474.20	401.55	128.36	54.49	58.82	43.96
IV (CO_2)	449.98	617.35	449.44	164.65	66.33	70.74	53.30
Total (CO_2)	**803.45**	**1091.55**	**850.99**	**293.00**	**120.82**	**129.56**	**97.27**

9.0 Conclusion:

The plantations done by MPRVVN in 480 hectares between 2019 and 2021 with the support of Havells India are located in the Vidisha and Sagar divisions of Madhya Pradesh. The survival rate of the plantation is more than 90% across the compartments, which is reflective of good management. The CO_2 sequestration potential of the plantation after the final harvest (60 years) would be 430700 tonnes. Additionally, it is important to mention here that these plantations will also produce good quality timber wood and contribute to other ecological benefits during the entire silvicultural management. The CO_2 sequestration of young Havells plantation varies between 97 and 1092 tonnes by considering various equations.

The assessment of biomass and carbon in any forest/plantation is done either through destructive or non-destructive methods. It is generally accepted that destructive methods are more precise and site-specific. In this regard, it is suggested that Forest Department record the height, diameter and dry biomass for different ages of trees while carrying out their thinning operation on a sample basis. These recorded data would help in developing more accurate allometric equations for biomass and carbon assessment.

References

1. 1t.Org. (n.d.). Expanding Green cover through social forestry, in the eco-fragile Araku region of Andhra Pradesh. Project Hariyali: Pledge by Mahindra Group. https://www.1t.org/pledges/project-hariyali. Accessed on 25 April, 2023.
2. Behera, M. K., & Mohapatra, N. P. (2015). Biomass accumulation and carbon stocks in 13 different clones of teak (Tectona grandis Linn. F.) in Odisha, India. Current World Environment, 10(3), 1011-1016.
3. Bichta, C. (2003). Corporate social responsibility: a role in government policy and regulation?
4. Bremer, L.L., Farley, K.A. Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effects of land-use transitions on plant species richness. Biodivers Conserv 19, 3893–3915 (2010). https://doi.org/10.1007/s10531-010-9936-4
5. Brown, S. (1997). Estimating biomass and biomass change of tropical forests: a primer (Vol. 134). Food & Agriculture Org.
6. Bukoski, J.J., Cook-Patton, S.C., Melikov, C. et al. Rates and drivers of aboveground carbon accumulation in global monoculture plantation forests. Nat Commun 13, 4206 (2022). https://doi.org/10.1038/s41467-022-31380-7
7. Canadas-L, ~ A., Andrade-Candell, J., Manuel Domínguez-A, J., Molina-H, C., Schnabel- D, O., Vargas-Hernandez, J.J., Wehenkel, C., 2018. Growth and yield models for teak planted as living fences in coastal Ecuador. Forests 9, 1–14
8. CDM. (2015). Small scale Chitrakoot JFM A/R CDM Project on degraded lands in Chitrakoot Forest Division, Uttar Pradesh, India.
9. Champion, H. G., & Seth, S. K. (1968). A revised survey of the forest types of India. Manager of publications.
10. Chaturvedi, R. K., & Raghubanshi, A. S. (2015). Allometric models for accurate estimation of aboveground biomass of teak in tropical dry forests of India. Forest Science, 61(5), 938-949.
11. Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Fölster H, Fromard F, Higuchi N, Kira T, Lescure JP, Nelson BW, Ogawa H, Puig H, Riera B, Yamakura T (2005)

Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145:87–99.

12. Chayaporn, P., Sasaki, N., Venkatappa, M., & Abe, I. (2021). Assessment of the overall carbon storage in a teak plantation in Kanchanaburi province, Thailand–Implications for carbon-based incentives. Cleaner Environmental Systems, 2, 100023.
13. Cuong, T., Chinh, T.T.Q., Zhang, Y., Xie, Y., 2020. Economic performance of forest plantations in Vietnam: Eucalyptus, Acacia mangium, and Manglietia conifera. Forests.
14. Devinsights, (n.d.). https://devinsights.co.in/environmental-sustainability-under-corporate-social responsibility-csr/. Accessed on 24/04/2023.
15. Fonseca, W., Alice, F.E., Rey-Benayas, J.M., 2012. Carbon accumulation in aboveground and belowground biomass and soil of different age native forest plantations in the humid tropical lowlands of Costa Rica. New for. 43, 197–211. https://doi.org/10.1007/s11056-011-9273-9
16. Giri, N., Rawat, L., & Kumar, P. (2014). Assessment of biomass carbon stock in a Tectona grandis Linn. f. plantation ecosystem of Uttarakhand, India. International Journal of Engineering, Science and Technology, 3(5), 46-53.
17. Harwood, C.E., Nambiar, E.K.S., 2014. Productivity of acacia and eucalypt plantations in southeast Asia. 2. Trends and variations. Int. For. Rev.
18. Herault, B., Ouallet, J., Blanc, L., Wagner, F., Baraloto, C., Ecologie, U.M.R., 2010. Growth responses of neotropical trees to logging gaps. J. Appl. Ecol. 47, 821–831. https://doi.org/10.1111/j.1365-2664.2010.01826.x
19. Holl KD, Brancalion PHS. Tree planting is not a simple solution. Science. 2020 May 8;368(6491):580-581. doi: 10.1126/science. aba8232. PMID: 32381704.
20. Houghton, R.A., 2003. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850-2000. Tellus 55B, 378–390 https://doi.org/10.3402/tellusb.v55i2.16764
21. Huong, V.D., Nambiar, E.S., Quang, L.T., Mendham, D.S., Dung, P.T., 2015. Improving productivity and sustainability of successive rotations of Acacia auriculiformis plantations in South Vietnam. South. For. a J. For. Sci. 77, 51–58.
22. IEA (2020), Implementing Effective Emissions Trading Systems, IEA, Paris https://www.iea.org/reports/implementing-effective-emissions-trading-systems,

License: CC BY 4.0. https://thecsrjournal.in/mahindra-csr-corporate-social-responsibility-activities-report/

23. IISD. (2023). 58th Session of the IPCC (IPCC- 58), Earth Negotiations Bulletin, A Reporting Service for Environment and Development Negotiations, Vol. 12 No. 819, https://enb.iisd.org/sites/default/files/2023-03/enb12819e_0.pdf. Accessed on 21/04/23
24. Indian State of Forest Report. (2021). References- Annexure- Contribute. https://fsi.nic.in/isfr-2021/refference-annxure-contribute.pdf
25. IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., http://doi:10.1017/9781009325844
26. ITC, (n.d.). ITC's agro-forestry initiatives to the aid of farmers. https://www.itcportal.com/media-centre/press-reports-content.aspx?id=2103&type=C&news=Itcs-agro-forestry-initiatives-to-the-aid-of-farmers.
27. Jha, K. K. (2015). Carbon storage and sequestration rate assessment and allometric model development in young teak plantations of tropical moist deciduous forest, India. Journal of forestry research, 26, 589-604.
28. Karmacharya, S. B., & Singh, K. P. (1992). Biomass and net production of teak plantations in a dry tropical region in India. Forest Ecology and Management, 55(1-4), 233-247. https://doi.org/10.1016/0378-1127(92)90103-G.
29. Ketterings, Q.M., Coe, R., Van Noordwijk, M., Ambagau, Y., Palm, C.A., 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. For. Ecol. Manag. 146, 199–209. https://doi.org/10.1016/S0378-1127(00)00460-6.
30. Koppad, A. G., & Rao, R. V. (2013). Influence of management practices on carbon sequestration in teak plantations. Karnataka Journal of Agricultural Sciences, 26(1), 85-87.

31. Kumi, J. A., Kyereh, B., Ansong, M., & Asante, W. (2021). Influence of management practices on stand biomass, carbon stocks and soil nutrient variability of teak plantations in a dry semi-deciduous forest in Ghana. Trees, Forests and People, 3, 100049.
32. Ladrach, W. (2009). Management of tea plantations for solid wood products. ISTF News, Special Report.
33. Mahindra. (4 June, 2021). World Environment Day 2021: How Club Mahindra's Hariyali Initiative Supports Environment & Local Communities. https://www.clubmahindra.com/blog/experience/world-environment-day-2021-mahindra-hariyali-initiative-supports-environment-and-local-communities. Accessed on 25 April, 2023
34. National CSR Portal (n.d.) https://www.csr.gov.in/content/csr/global/master/home/home/csr-spent--developmentsectorwise.html?=Environment,%20Animal%20Welfare,%20Conservation%20of%20Resources=FY%202020-21.
35. Negi, M., Tandon, Y., & Rawat, H. (1995). Biomass and Nutrient Distribution in Young Teak (Tectona grandis Linn. F) Plantations in Tarai Region of Uttar Pradesh. Indian Forester, 121(6), 455-464. doi:10.36808/if/1995/v121i6/7161.
36. Nirala, D., Khanduri, V. P., & Sankanur, M. S. (2018). Biomass and carbon stock assessment in different age group plantations of teak (Tectona grandis Linn. F.) in Bhabar and Shivalik regions of Uttarakhand. International Journal of Bio-resource and Stress Management, 9(3), 379-382.
37. OECD (2003). Policies to Reduce Greenhouse Gas Emissions in Industry - Successful Approaches and Lessons Learned: Workshop Report. https://www.oecd.org/environment/cc/2956442.pdf. Accessed on 25 April, 2023.
38. Onkar, S., & Khare, P. K. (2016). Aboveground biomass and carbon stock of tropical deciduous forest ecosystems of Madhya Pradesh, India. International Journal of Ecology and Environmental Sciences, 42(5), 75-81.
39. Ontl, T.A., Janowiak, M.K., Swanston, C.W., Daley, J., Handler, S., Cornett, M., Hagenbuch, S., Handrick, C., Mccarthy, L., Patch, N., Ontl, T.A., Janowiak, M.K., 2020. Forest management for carbon sequestration and climate adaptation. J. For. 86–101

40. Pandya, I. Y., Salvi, H., Chahar, O., & Vaghela, N. (2013). Quantitative analysis on carbon storage of 25 valuable tree species of Gujarat, Incredible India. Indian Journal of Scientific Research, 4(1), 137-141.
41. Pati, P. K., Kaushik, P., Khan, M. L., & Khare, P. K. (2022). Allometric equations for biomass and carbon stock estimation of small diameter woody species from tropical dry deciduous forests: Support to REDD+. Trees, Forests and People, 9, 100289
42. Payn, T., Carnus, J. M., Freer-Smith, P., Kimberley, M., Kollert, W., Liu, S., ... & Wingfield, M. J. (2015). Changes in planted forests and future global implications. Forest Ecology and Management, 352, 57-67. https://doi.org/10.1016/j.foreco.2015.06.021
43. Raha, D., Dar, J. A., Pandey, P. K., Lone, P. A., Verma, S., Khare, P. K., & Khan, M. L. (2020). Variation in tree biomass and carbon stocks in three tropical dry deciduous forest types of Madhya Pradesh, India. Carbon Management, 11(2), 109-120
44. Reddy, M. C., Priya, R. M., & Madiwalar, S. L. (2014). Carbon sequestration potential of Teak plantations of different agro-climatic zones and agegradations of Southern India. Current World Environment, 9(3), 785-788.
45. Sreejesh KK, Thomas TP, Rugmini P, Prasanth KM, Kripa PK (2013) Carbon sequestration potential of teak (Tectona grandis) plantations in Kerala. Res J Recent Sci 2:167–170
46. Usuga, C.J.L., Toro, J.A.R., Alzate, R.V.M., Tapias, L. de J.A., 2010. Estimation of biomass and carbon stocks in plants, soil and forest floor in different tropical forests. For. Ecol. Manage. 260, 1906–1913.
47. Vikaspedia. (n.d.). Teak. https://vikaspedia.in/agriculture/forestry/tree-crops/teak
48. Wang, J.K., Zhong, A.L., Comeau, P., Tsze, M., Kimmin, J.P., 1995. Above ground biomass and nutrient accumulation in an age sequence of aspen (Populus tremuloides) in the boreal white and black spruce zone, British Columbia. For. Ecol. Manag. 78, 127–138. https://doi.org/10.1016/0378-1127(95)03590-0
49. Wirabuana, P. Y. A. P., Hendrati, R. L., Baskorowati, L., Susanto, M., Mashudi, Budi Santoso Sulistiadi, H., ... & Alam, S. (2022). Growth performance, biomass accumulation, and energy production in age series of clonal teak plantation. Forest Science and Technology, 18(2), 67-75.

50. Yahya, A. Z., Saaiffudin, K. A., & Hashim, M. N. (2011). growth response and yield of plantation-grown teak (TecTona grandis) after low thinning treatments at pagoh, peninsular malaysia. Journal of Tropical Forest Science, 453-459. https://www.jstor.org/stable/23617059