Knowledge, evidence and learning for development

Carbon Abatement Potential of Reforestation

Dylan O'Driscoll
University of Manchester
20 November 2018

Questions

What is the carbon abatement potential of reforestation relative to other mitigation measures?

What is the best practice on reforestation, i.e. what works best according to the evidence?

Contents

1. Summary

This rapid review synthesises the literature from academic, policy and NGO sources on the carbon abatement potential of reforestation. The literature points to the significant potential to reduce carbon through reforestation, specifically if it is paired with good forest management and the reduction of deforestation. It is argued that these natural methods of carbon abatement, paired with lifestyle changes and advances in technology and farming could meet the requirements under the Paris Agreement.

Key findings are as follows:

- Reforestation, afforestation, reduced deforestation and sustainable forest management can increase carbon sequestration whilst at the same time supplying sustainable wood products that replace more carbon-intense products in different supply chains.
- Forestry has the greatest natural potential for carbon abatement, regardless of the carbon price.[1]
- Reforestation, has the potential to reduce carbon by over three billion metric tonnes a year at a 2030 reference year, but this involves all grazing land in forested eco regions being reforested (Griscom et al., 2017: 11646).
- All forest-related methods have the potential of reducing 11.3 billion metric tonnes of carbon per year by 2030, which is equivalent of halting global oil consumption and would result in one-third of the reduction necessary to limit global warming to 2 degrees C by 2030.
- Although reforestation can be costly, the cost can be reduced through private sector reforestation activities that establish plantations for an initial commercial harvest to facilitate natural and assisted forest regeneration.
- Reforestation also has a number of extra benefits, such as, bio-diversity habitat, air filtration, water filtration, flood control, and enhanced soil fertility.
- According to the FAO (2016) the total mitigation potential of afforestation, reducing deforestation and forest management could range from 1.9 to 5.5 gigatonnes (Gt) of CO2 emissions per year by 2040 at a carbon value of less than US$20 per tonne.
- The ability to sell carbon credits has a significant impact on the viability of reforestation, as it makes more land economically viable for reforestation and up-front carbon payments to landowners is also favourable, as it helps them address the costs.
- Large areas of agricultural land could become more profitable as carbon sinks through forestry at relatively modest carbon prices.

Reforestation and forestry practices:

- Reforestation needs to include good forest management, as it is essential for both carbon and forest productivity. Forest management practices need to address the soil carbon pool, as the soil in forests hold 39% of the carbon stored.

[1] This is the price that companies must pay per a tonne of carbon emissions, and based on this price carbon credits can be bought to reduce the carbon footprint.

- Good forest management includes the modification of rotation length; avoiding losses from pests, disease, fire and extreme weather; managing the soil carbon pool; and maintaining biodiversity.
- Preventing fires through forest management is particularly important, as annual global emissions from wild land fires are around 7.34 Gt CO2 (FAO, 2016).
- Forest management offers the best mitigation option owing to its ease of implementation and short timescale.
- The productivity and carbon sequestration potential of forests depends on climate zones and forest types. Monocultures of production trees generally accumulate biomass faster, but do not offer biodiversity and are less resilient to dramatic climate changes.
- Studies have shown that trees produce more biomass in mixed-species plantings than in single-species planting due to less competition between species than within species, however for productivity the compatibility of the different species is important.
- The choice of trees also determines growth rates, as the inclusion of nitrogen-fixing trees increases productivity during early development.
- Soil provides a more stable carbon store than plant biomass and continues to accumulate carbon after forest maturity and reforestation on degraded soils can double soil carbon content.
- For carbon sequestration in soil the species type is very important, with the largest increases under broadleaf species (27%), average with eucalypts (12%) and little change under conifers (2%).
- It is recommend planting a mosaic of production-tree monocultures for biomass accumulation, diverse native plantings of trees and shrubs for biodiversity, and mixed plantings of productive native tree species for both carbon and biodiversity.
- Research shows that planting a mix of trees increases the carbon capture of the forests and begins the process quicker.
- It is important that reforestation projects improve the livelihoods of rural communities that rely on the land for their income and this can be achieved through good forest management.
- It is important that locals are involved in tree selection, as the fastest growing trees or those with the greatest economic value are not necessarily the most suitable. Locals also need to be involved in choosing the most suitable land for reforestation.
- If locals are dependent on the land for livelihoods, then alternative income generating schemes need to be provided.
- Deforestation happens because there is a demand for wood products and thus alternatives need to be provided to prevent illegal logging.
- To be effective, reforestation strategies need to be coupled with improved governance through the enforcement of applicable laws and regulations**.**
- Agroforestry can help farmers restore degraded land, increase productivity and diversify their income, whilst at the same time increasing carbon storage in both the soil and the trees, the FAO argue that it is the most reliable way to guarantee food security.

2. Potential of Reforestation

According to the FAO (2016), in a best-case scenario, reforestation, afforestation, reduced deforestation and sustainable forest management would enable increased carbon sequestration whilst at the same time supplying sustainable wood products that replace more carbon-intense products in the different supply chains, specifically construction. For example, the use of wood-based building materials avoids emissions of 483 million tonnes CO2e annually via substitution effects. In addition, by displacing fossil fuels, the burning of used products at the end of the life cycle avoids the emission of more than 25 million tonnes CO2e annually, which could be increased to 135 million tonnes by diverting material from landfills. Figure 1 demonstrates the various carbon benefits of forestry-related abatement methods. Whereas Figure 2 demonstrates the carbon abatement potential of the different land use mechanisms based on the carbon price per tonne of 30, 50 and 100 US dollars across the various regions. This graph demonstrates the significant potential of forestry for carbon abatement, particularly with a carbon price of 100 US dollars per a tonne.

Figure 1: Carbon benefits of forestry-related abatement methods

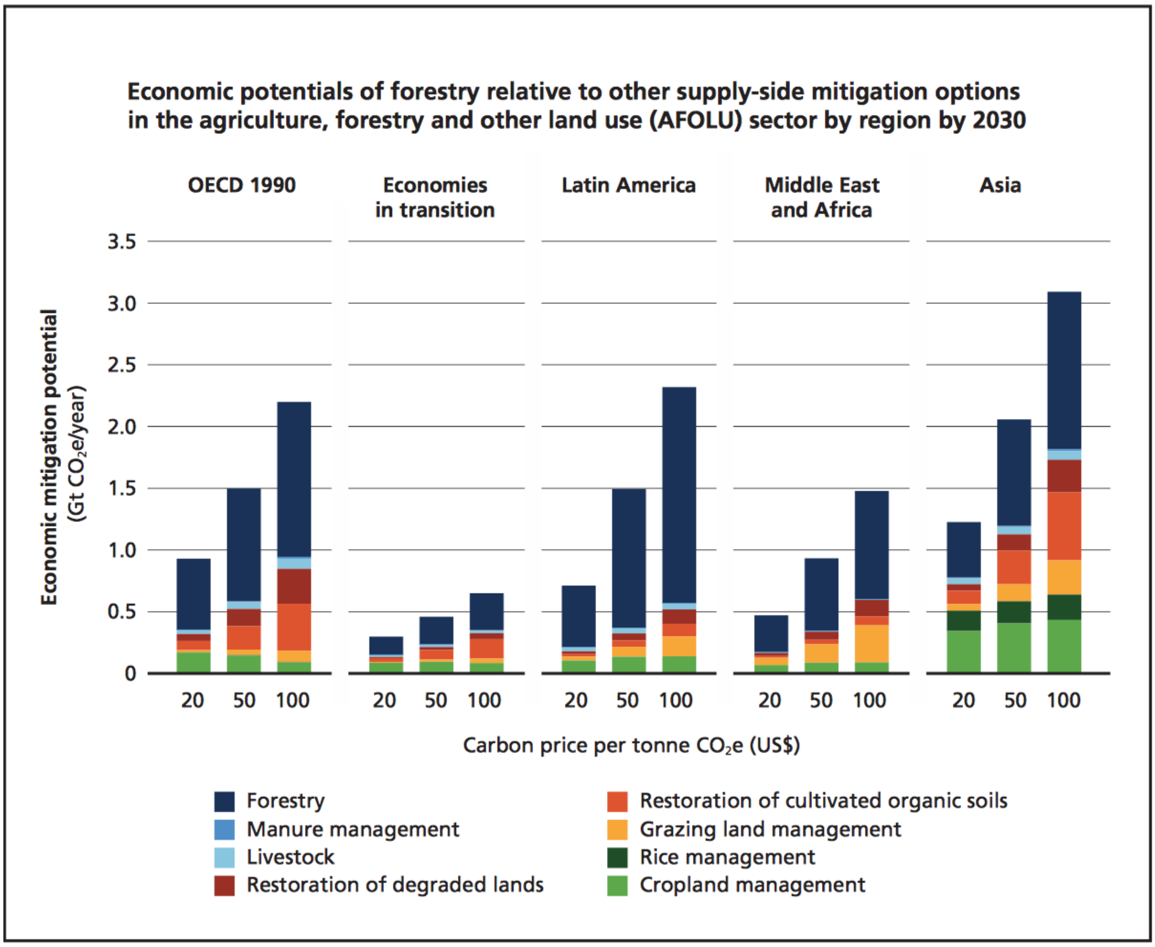
Key forest-sector mitigation options assessed in this publication

Activity	Mitigation action	Examples	Carbon benefits
Aimed at enhancing carbon stocks (i.e. sinks)			
Afforestation and reforestation	Increasing the forest area	Planting new forests	Increases atmospheric CO_2 removal from long-term forest stocks and tree plantations Augments the availability of HWPs, including for bioenergy use
Forest management	Increasing the carbon density/stock in forests	Optimizing the use of appropriate fertilizers and irrigation Restoring degraded forests and soils Optimizing harvest systems and implementing reduced-impact harvesting Managing impacts of forest disturbances under a changing climate	Maximizes CO_2 removal and storage Enables long-term production of HWPs for bioenergy or other uses
Green building and furnishing	Replacing high-energy products with industrial wood products	Using wood and forest-based materials for green buildings, infrastructure and furniture	Increases carbon storage potential off-site through the use of HWPs
Aimed at reducing GHG emissions (i.e. sources)			
Reduced deforestation and degradation (REDD)	Maintaining forest area and site- and landscape-scale carbon stocks/density	Preventing forest loss Suppressing forest disturbance via better management of fires, pests and diseases Improving management of soil carbon	Helps avoid GHG emissions and maintain CO_2 removal and optimal forest stock
Use of wood energy	Improving practices related to bioenergy	Using sustainably produced wood products and residues for energy Promoting improved cookstoves	Avoids CO_2 emissions through substitution of fossil-fuel-based energy Avoids emissions from microbial decomposition of biomass
Green building and furnishing	Improving use and uptake of wood-based products	Using climate-smart products following a cascading principle, including increased use of wood in construction	Avoids CO_2 emissions through substitution of fossil-fuel-based products by green buildings and bio-based materials and chemicals Avoids emissions from microbial decomposition of biomass

Note: Options may not be mutually exclusive.

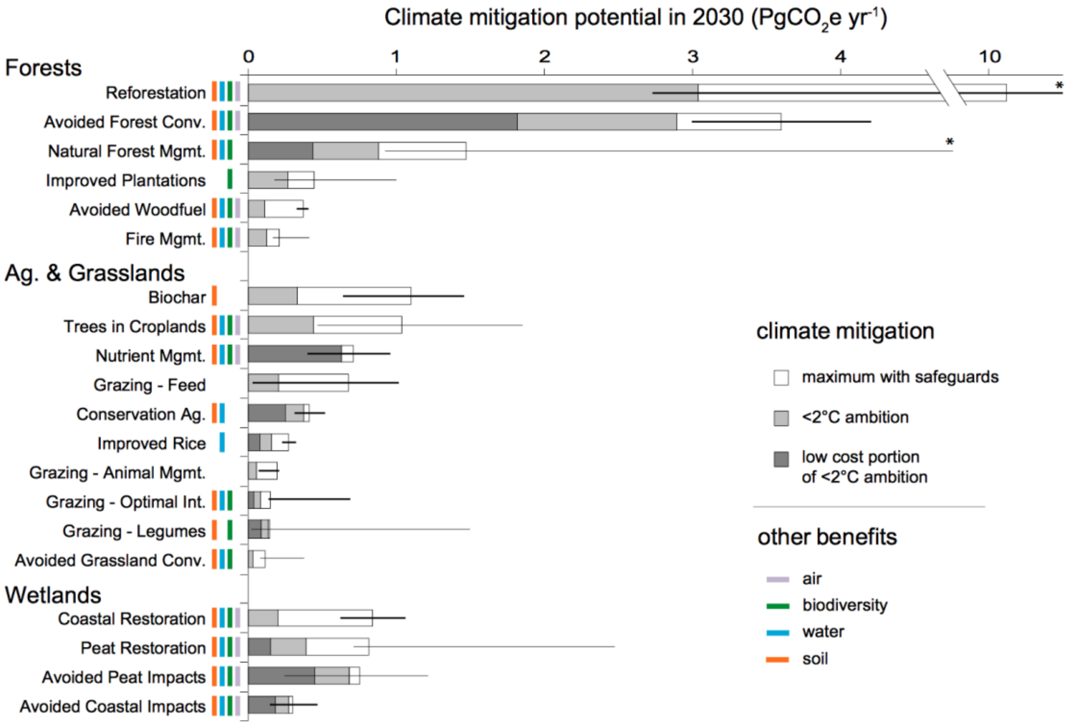
FAO, 2016: 6

Figure 2: Carbon abatement potential of the different land use mechanisms



FAO, 2016: 20

Figure 3: Natural carbon mitigation options



Griscom et al., 2017: 11646

Examining natural carbon mitigation options that safeguard the production of food and fibre and habitat for biological diversity, Griscom et al. (2017) put forward the most feasible options. They find that the maximum potential of these natural options is 23.8 PgCO2e[2] y−1 at a 2030 reference year. This amount is not constrained by costs, but rather the increased human needs for food and fibre. In reaching this maximum potential scenario there is no reduction in existing cropland, but grazing lands in forested eco regions are reforested. Of theses natural elements reforestation has the potential to make the biggest impact, followed by avoiding forest conversion and natural forest management, as visualised in Figure 3.[3] The forest options available account for over two thirds of the cost-effective options and half the low cost options. Reforestation has the potential to make the biggest impact in carbon reduction out of the natural options available. However, it can involve trade-offs with alternative land uses, can be costly to establish, and is more expensive than avoiding forest conversion. Nonetheless, there are opportunities to reduce costs, such as private sector reforestation activities that establish plantations for an initial commercial harvest to facilitate natural and assisted forest regeneration. Additionally, reforestation has a number of extra benefits, such as, bio-diversity habitat, air filtration, water filtration, flood control, and enhanced soil fertility. The maximum reforestation mitigation potential estimated by Griscom et al. (2017) is dependent on all grazing land in forested eco regions being

---

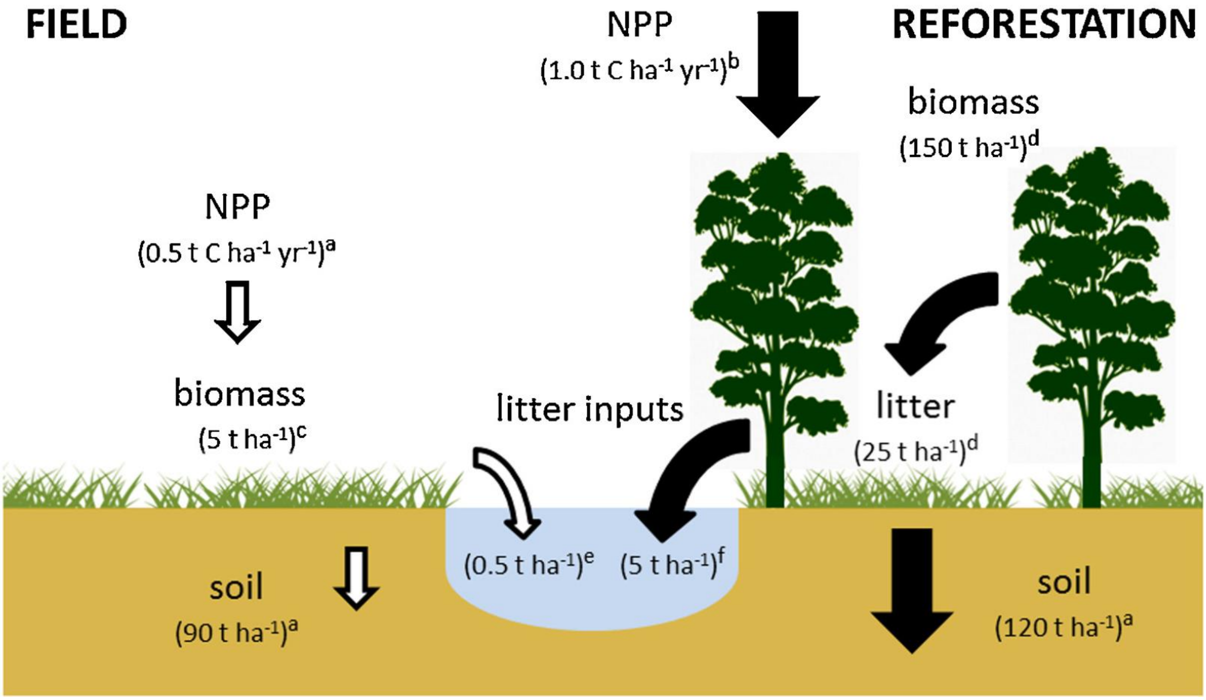
[2] One Pg = one billion metric tonnes

[3] Light grey portions of bars represent cost-effective mitigation levels assuming a global ambition to hold warming to <2 °C (<100 USD MgCO2e−1 y−1). Dark grey portions of bars indicate low cost (<10 USD MgCO2e−1 y−1) portions of <2 °C levels. White portions of bars represent maximum potential without financial constraints, but with safeguards.

reforested. If 25%, 50%, or 75% were not reforested, it would result in 10%, 21%, and 31% reductions respectively. 42% of reforestation opportunities they identify are located on lands now used for grazing within forest eco regions, however at the <2 °C ambition mitigation level this would only displace 4% of global grazing lands. The decrease in grazing land can be counteracted through better grazing management and/or the reduction of beef in people's diets (Griscom et al., 2017). Additionally, forest-based products from reforestation, such as nuts, fruit and wild game can be utilised to lower the impact of the loss of grazing land.

Along with reforestation, the avoidance of deforestation is also important, especially as it has the potential to deliver more than 40% of total emissions reductions offered by low-cost solutions (less than $100 per ton of carbon dioxide), as demonstrated in Figure 3. Brazil and Indonesia together contribute more than 50% of tree cover loss-based carbon emissions across the tropics, and therefore offer the opportunity for targeted programmes to avoid deforestation. The forest-related natural carbon mitigation options could collectively reduce 11.3 billion metric tons of greenhouse gas emissions per year. This reduction is the equivalent of halting global oil consumption and would result in one-third of the reduction necessary to limit global warming to 2 degrees C by 2030 (Minnemeyer et al., 2017). Figure 4 demonstrates the difference between a field and a forest with regards to carbon abatement.

Figure 4: Carbon abatement in fields and forests



Cunningham et al.,2015: 308

3. Cost

Cost and Carbon Reduction

Bioenergy with carbon capture and storage (BECCS)[4] is largely untested and it is argued that many of the options are actually unfeasible. It is however argued that natural methods of carbon abatement can help reduce carbon to the required levels.[5] BECCS has also not been proven at a commercially viable scale and caution has been urged as to whether it is actually a viable option. Other methods such as air capture are nowhere near being implemented or being financially viable. It is therefore difficult to give an accurate assessment of the potential cost of these methods.[6] Carbon capture and storage of fossil fuel-based energy production is also extremely expensive and has thus far not entered mainstream use. Some plants that are operational, such as those of Climeworks, are capturing carbon for between US$600-800. However, it is estimated that with technological advancements the price per a tonne of carbon abated is estimated to decline to between US$ 40-57 by the early 2020s. In early 2018 researchers made a break through in capturing carbon and claimed to be able to do it for US$94 per a tonne, although this has not been tested at a large scale.[7] These methods also do not take existing carbon out of the air and reforestation and forest management are methods that are available now, relatively cheaply, and with added benefits.

According to the FAO (2016) the total mitigation potential of afforestation, reducing deforestation and forest management could range from 1.9 to 5.5 gigatonnes (Gt) of CO2 emissions per year by 2040 at a carbon value of less than US$20 per tonne. Figure 5 demonstrates the potential for carbon abatement through forests in the different regions at the different carbon prices.

[4] BECCS produces negative carbon dioxide emissions by combining bioenergy use with geologic carbon capture and storage.

[5] https://www.carbonbrief.org/explainer-10-ways-negative-emissions-could-slow-climate-change

[6] https://www.carbonbrief.org/explainer-10-ways-negative-emissions-could-slow-climate-change

[7] https://www.power-technology.com/features/carbon-capture-cost/

Figure 5: Forest-based carbon abatement at the different carbon prices

Economic potential for forest-based mitigation options in 2030, from global models

Region/group	Afforestation				Reduced deforestation				Forest management				Total[b]
	Potential at cost up to US$100 (*Mt CO_2e/ year*)	% of total potential at different cost ranges in US$/ tonne CO_2			Potential at cost up to US$100 (*Mt CO_2e/ year*)	% of total potential at different cost ranges in US$/ tonne CO_2			Potential at cost up to US$100 (*Mt CO_2e/ year*)	% of total potential at different cost ranges in US$/ tonne CO_2			
		1–20	20–50	50–100[a]		1–20	20–50	50–100[a]		1–20	20–50	50–100[a]	
Africa	665	70	16	14	1 160	70	19	11	100	65	19	16	1 925
Central and South America	750	39	33	28	1 845	47	37	16	550	43	35	22	3 145
United States of America	445	30	30	40	10	20	30	50	1 590	26	32	42	2 045
East Asia (non-Annex I)	605	26	26	48	110	35	29	36	1 200	25	28	47	1 915
Other Asia	745	39	31	30	670	52	23	25	960	54	19	27	2 375
Middle East	60	50	26	24	30	78	11	11	45	50	25	25	135
OECD Pacific	115	24	37	39	30	48	25	27	110	20	35	45	255
Europe	115	31	24	45	10	17	27	56	170	30	19	51	295
Countries in transition	545	35	30	35	85	37	22	41	1 055	32	27	41	1 685
Total	**4 045**	**40**	**28**	**32**	**3 950**	**54**	**28**	**18**	**5 780**	**34**	**28**	**38**	**13 775**

[a] Calculated from the two columns to the left.
[b] Top-down global estimates of mitigation from wood energy and green building are not available in Nabuurs *et al.*, 2007.

FAO, 2016: 21

Different types of trees reduce carbon at various levels and involve different management techniques (see Figure 6 and 7). Long rotation hardwoods reduce carbon at a greater level than carbon planting, but are only suitable for some areas and involve more management and operation costs. They do however also result in a sellable product (See Figure 8, prices in Australian Dollars). The ability to sell carbon credits has a significant impact on the viability of reforestation, as it makes more land economically viable for reforestation. However, as part of the assessment for financial viability the types of trees that are most suitable for the area need to be planted. One key point is that an increase in the price of carbon credits generally makes more land financially viable for reforestation and the increase of viable land is at a higher rate than the financial increase (ABARES, 2011).

Figure 6: Carbon sequestration of long rotation hardwoods

Long rotation hardwoods Region	species	rotation years	MAI a m^3/ha.yr	carbon dioxide sequestration tCO_2-e/ha.yr b
Central Gippsland	*E. nitens*	45	9	14.5
Central Victoria	*E. globulus*	45	9	14.5
Green Triangle	*E. globulus*	25	14	24.2
Murray Valley	*E. globulus*	45	9	14.5
North Coast	North Coast eucalyptus	45	9	14.5
Northern Queensland	North Coast eucalyptus	45	9	14.5
Northern Tablelands	North Coast eucalyptus	45	9	14.5
South East Queensland	North Coast eucalyptus	45	9	14.5
Tasmania	*E. nitens*	25	14	24.2
Western Australia	*E. globulus*	25	14	24.2
South Australia (Mt Lofty)	*E. globulus*	25	14	24.2

ABARES, 2011: 9

Figure 7: Carbon sequestration of carbon planting trees

Carbon plantings Region		m^3/ha.yr	tCO_2-e/ha.yr c
Bombala – East Gippsland	Mixed native	3.3	7.6
Central Gippsland	Mixed native	3.3	7.5
Central Tablelands	Mixed native	2.3	5.3
Central Victoria	Mixed native	2.2	5
Green Triangle	Mixed native	2.1	4.9
Murray Valley	Mixed native	2.2	5
North Coast	Mixed native	4.4	10
Northern Queensland	Mixed native	3.2	7.4
Northern Tablelands	Mixed native	2.5	5.8
Southern Tablelands	Mixed native	2.1	4.8
South East Queensland	Mixed native	2.9	6.5
Tasmania	Mixed native	2.8	6.3
Western Australia	Mixed native	1.1	2.4
South Australia	Mixed native	1.9	4.3
Northern Territory	Mixed native	2	4.6
Rest of NSW	Mixed native	1.1	2.6
Rest of Victoria	Mixed native	1.2	2.7
Rest of Queensland	Mixed native	0.7	1.5

ABARES, 2011: 9

Figure 8: Cost and income of forests

			LRHW timber plantations a	carbon plantings
Establishment costs	\$/ha	year 1	2 740	3 200
Management costs	\$/ha.yr	year 2–30	200	150
		year 30+	200	50
Roading	\$/ha	year of first thinning	300	na
Marking	\$/ha	each thinning	100	na
Harvesting	\$/m³	thinning and harvesting	22	na
Transport	\$/m³.km	forest to mill	0.2	na
Log price	\$/m³	at mill-door b	61–87	na

ABARES, 2011: 10

Torres et al. (2010) argue that in order to increase reforestation there needs to be a negotiation of higher carbon payments and the investment in high quality baselines to enable landowners to participate and reduce transaction costs. They also favour up-front carbon payments to landowners, as this helps them address the costs. Finally, for them, agroforestry is a useful way of introducing forestry without changing land-use or negatively impacting on food production.

Using the case study of Australia, Paterson and Bryan (2012) argue that large areas of agricultural land could become more profitable as carbon sinks through forestry at relatively modest carbon prices. For example, at a carbon price of 27 Australian dollars tCO2-e nearly one-third of their study area (1.99 Mha) becomes more profitable for carbon sequestration and at 58 Australian dollars, all of the study area is more profitable.

4. Reforestation Practices

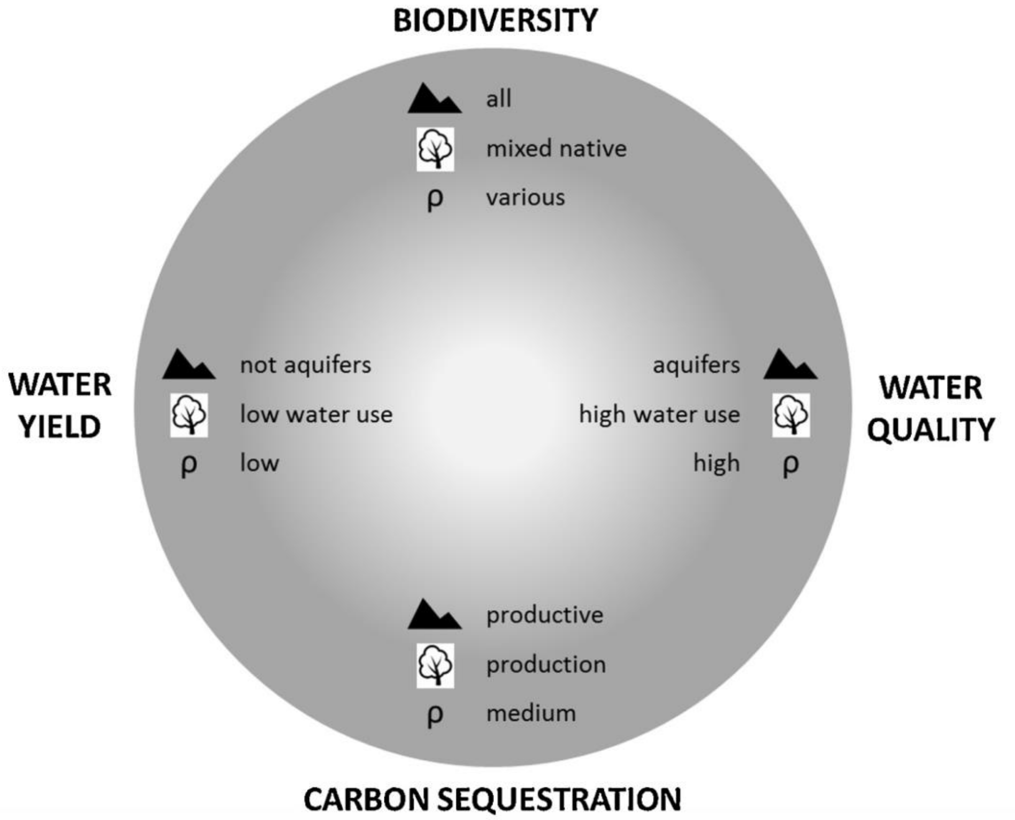
Good forest management is essential for both carbon and forest productivity and to address potential risks from pests, disease, fire and extreme weather, as well as maintaining biodiversity. The soil in forests hold 39% of the carbon stored in soil and thus management practices need to address the soil carbon pool. Afforestation of former agricultural land is also thought to increase the carbon pool in biomass, soil and dead organic matter (dead wood and litter). However, a number of factors, such as previous land use, tree species planted, soil clay content, pre-planting disturbance and climatic zone also need to be taken into account. It is also important that forests are properly managed in order to increase carbon sequestration and storage and reduce emissions. This includes the modification of rotation length; avoiding losses from pests, disease, fire and extreme weather; managing the soil carbon pool; and maintaining biodiversity. Fire management is of particular importance, as annual global emissions from wild land fires are around 7.34 Gt CO2. Fires affect around 350 million hectares annually and there is an increase in fires in tropical forests, which is directly related to deforestation and land-use change. In order to maximise the mitigation potential of forests the focus should not only be on enhancing their capacity as a carbon sink and reducing their human-induced emissions, but also on promoting cost-efficient technologies with low carbon intensity and implementing proper and sustainable forest management. Forest management is extremely important, as forests are currently responsible for about 10 to 12% of global emissions. Forest management offers the best mitigation option owing to its ease of implementation and short timescale. In developed countries afforestation and reforestation offer the highest forest mitigation potential, whereas in developing countries the largest potential is in the reduction of deforestation and forest degradation (FAO, 2016).

According to Cunningham et al. (2015) how reforestation is approached has long-term consequences with compromises between the structure and function of the forest. Therefore there are a number of decisions that need to be made before reforestation begins. Such as, the amount and types of trees planted and if shrubs are also planted, as there are a number of outcomes dependent on these decisions. For instance, fast-growing production species sequester carbon faster than native mixed-species but often have little biodiversity value; reforestation of riparian zones may increase biodiversity, but it also reduces the stream flow; permanent restoration provides more environmental benefits than harvested plantations, but do not offer wood products. The secondary purpose of the forest also needs to be taken into account – is it just for carbon abatement, or is it meant to create biodiversity, or be logged?

Carbon sequestration following reforestation is dependent on the balance between the accumulation of biomass and litter, losses from respiration and decomposition of litter, and soil carbon. The productivity and carbon sequestration potential of forests depends on climate zones and forest types. Monocultures of production trees generally accumulate biomass faster than native tree species due to tree breeding and control of the forests. However, in low-rainfall areas (less than 800 mm per year) native species are equally productive and less vulnerable to drought. Studies have shown that trees produce more biomass in mixed-species plantings than in single-species planting due to less competition for between species than within species. However, higher diversity does not necessarily mean increased productivity, as outcomes depend on the productivity of the site and compatibility of the different species. The choice of trees also determines growth rates, as the inclusion of nitrogen-fixing trees increases productivity during early development.

Soil generally provides a more stable carbon store than plant biomass and continues to accumulate carbon after forest maturity. Following the conversion of forest to agriculture there are substantial decreases in soil carbon, which reforestation can reverse, however this does take a significant amount of time. For carbon sequestration in soil the species type is very important, with the largest increases under broadleaf species (27%), average with eucalypts (12%) and little change under conifers (2%). Whilst planting in higher productivity regions leads to faster accumulation of biomass, reforestation on degraded soils can double soil carbon content. In order to get the best benefit of the various tree types Cunningham et al. (2015) recommend planting a mosaic of production-tree monocultures for biomass accumulation, diverse native plantings of trees and shrubs for biodiversity, and mixed plantings of productive native tree species for both carbon and biodiversity. If the main purpose is to maximise carbon sequestration then plantations should focus on production species on the most productive land at medium densities, as per Figure 9. However, research does show that planting a mix of trees increases the carbon capture of the forests and begins the process quicker. The study suggests that diverse forests store twice as much carbon as monoculture forests and the increase is seen both above and below ground. The authors thus argue that reforestation should move away from its focus on monocultures and instead focus on planting a mixture of tree species in order to increase carbon fixation (Liu et al., 2018).

Figure 9: Types of trees for different purposes



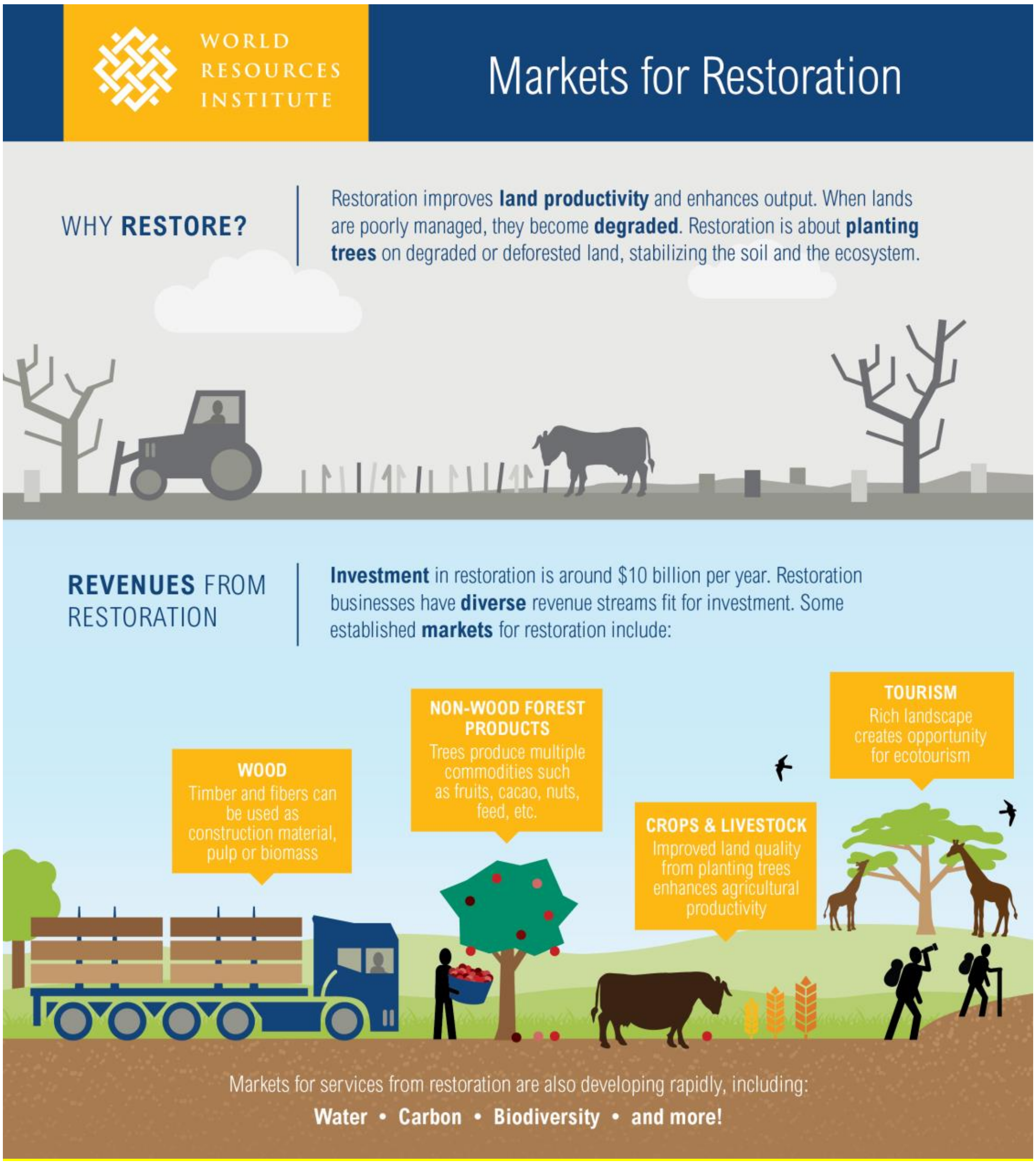
Cunningham et al.,2015: 312

Chemonics, a development implementation organisation, have put forward a number of recommendations for reforestation practices (Kerby, 2018). These are:

- **Involve local stakeholders from the beginning:** it is important that locals are involved in tree selection, as the fastest growing trees or those with the greatest economic value are not necessarily the most suitable. If trees are needed for income, then it is important that this can be generated quickly, or they will be cut down. Locals also need to be involved in choosing the most suitable land for reforestation.
- **Alternative means of livelihood should be provided while trees are growing:** if locals are dependent on the land for livelihoods, then alternative income generating schemes need to be provided.
- **Identify alternatives for those with a vested interest in cutting trees:** Deforestation happens because there is a demand for wood products and thus alternatives need to be provided to prevent illegal logging.

- **Work with local governments to enforce laws and improve governance:** to be effective, reforestation strategies need to be coupled with improved governance through the enforcement of applicable laws and regulations**.**

Figure 10: Income from forests



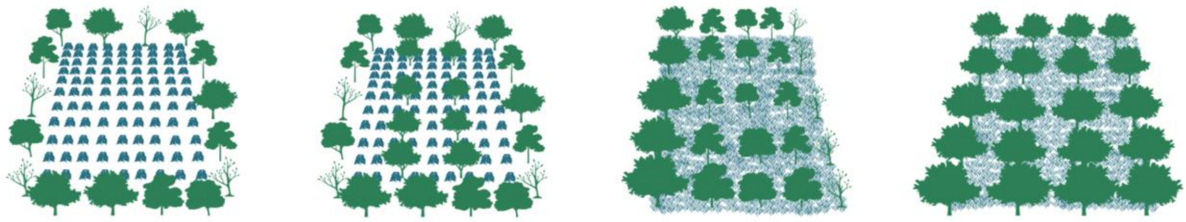
Faruqi & Wu, 2016

It is important that reforestation projects improve the livelihoods of rural communities that rely on the land for their income. This can be achieved through good forest management. Figure 10 demonstrates the positive impact forests can have on local incomes.

Agroforestry

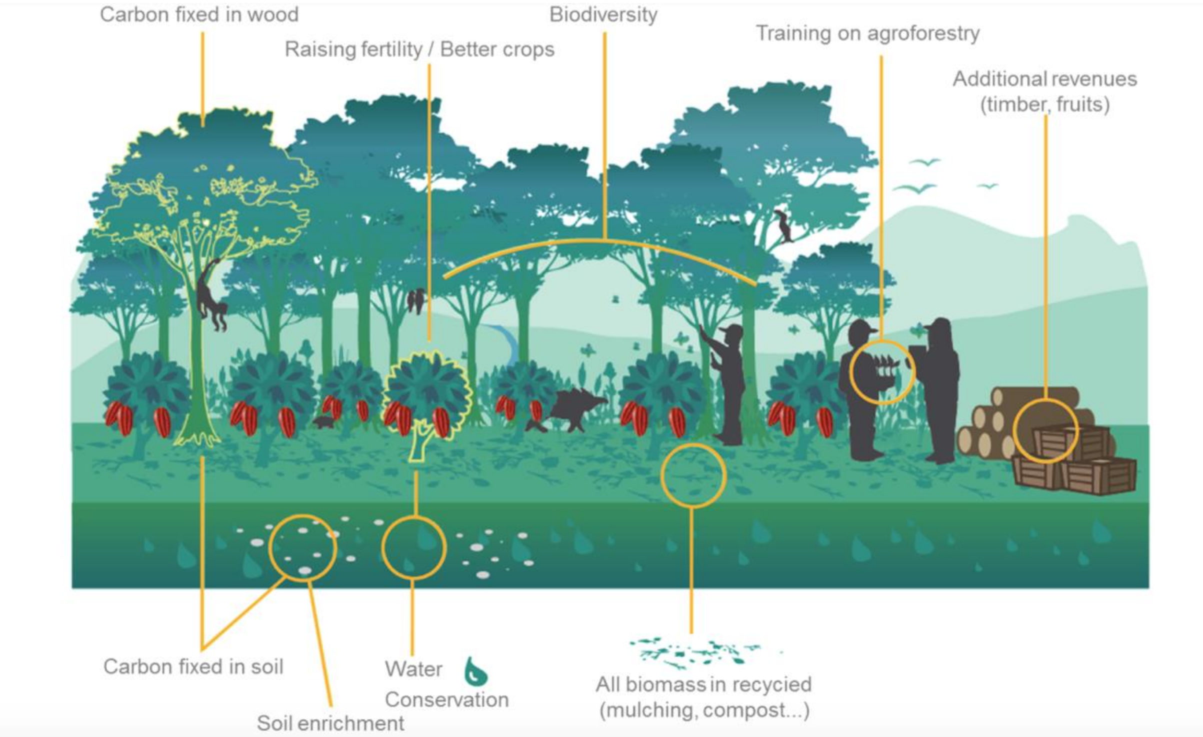
The FAO argues that agro-ecology is the most reliable way to guarantee food security. As well as creating carbon stores, it also helps prevent catastrophic erosion, climatic instability, and desertification. Agroforestry refers to the integration of trees into farming systems and it is a way to preserve productive ecosystems and adapt to climate change (Pur Project, 2016). Figure 11 demonstrates the different agroforestry models available. Agroforestry can help farmers restore degraded land, increase productivity and diversify their income, whilst at the same time increasing carbon storage in both the soil and the trees, as evident in Figure 12.

Figure 11: Types of agroforestry



Source: Pur Project, 2016

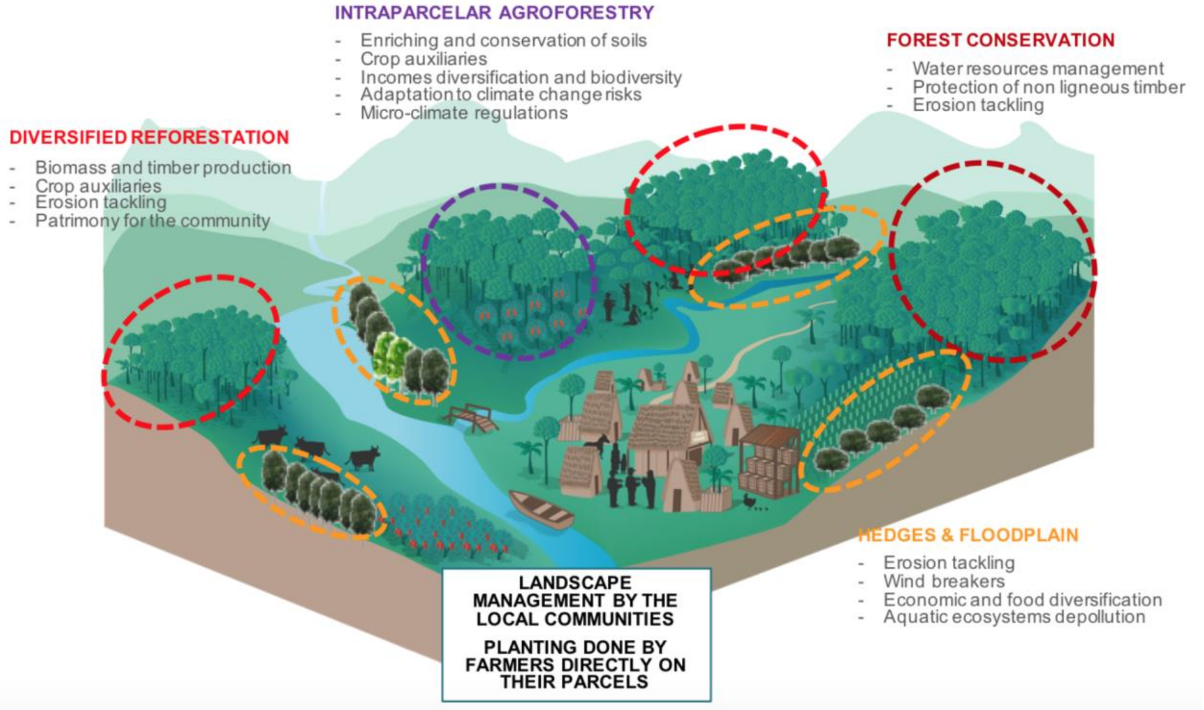
Figure 12: Benefits of agroforestry



Source: Pur Project, 2016

Mixing agroforestry with local-led forest conservation has the best results in terms of food production, ecosystem balance, and carbon storage, as evident in Figure 13.

Figure 13: Agroforestry and forestry plan and benefits



Source: Pur Project, 2016

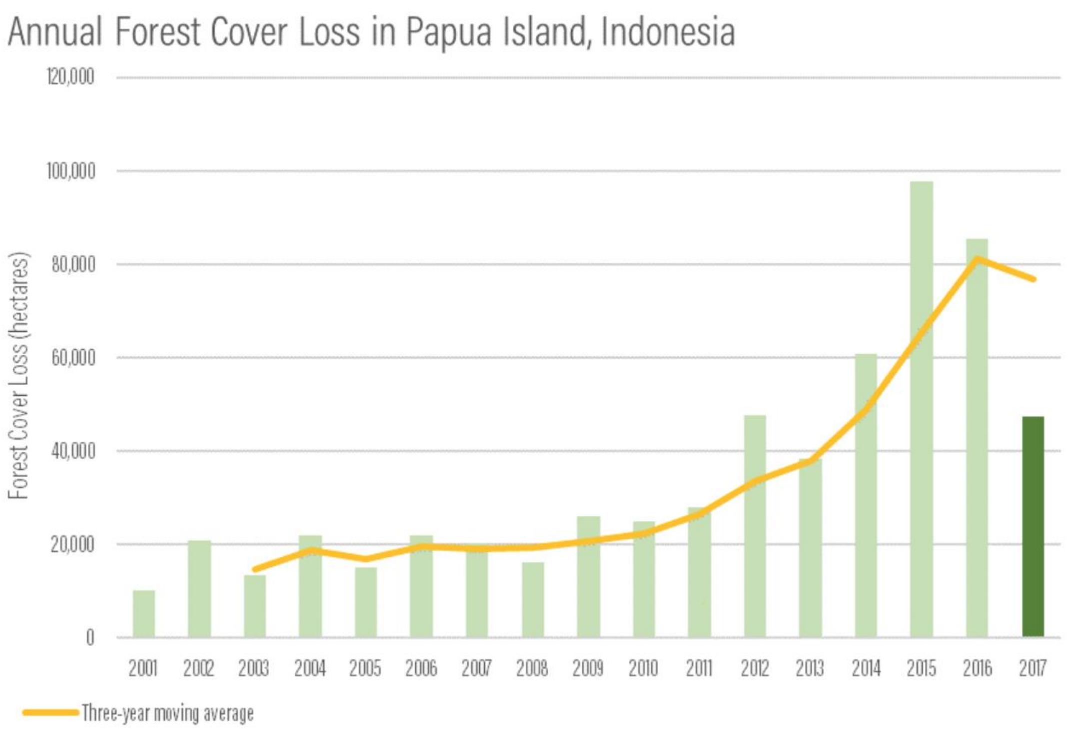
5. Case Studies

Indonesia

World Resources Institute (WRI) estimate that if Indonesia can maintain a minimum of 70% of Indonesian Papua as a conservation area and restore degraded lands in protected areas it could avoid 2.8–3.3 gigatons of carbon dioxide emissions and significantly exceed the Paris Agreement target of avoiding 1.8-2.0 gigatons of carbon dioxide by 2030. In order to make this feasible it is important to connect forestry to economic growth. For example, there is significant potential for ecotourism in Indonesian Papua and integrated agroforestry can expand the production of non-timber forest goods, like rubber, cocoa, honey, orchids and fruits. There is also significant potential for reforestation, as degraded and unproductive land surpassed 2 million hectares in 2013. Customary forests is also a good way to manage forests in Indonesian Papua, as indigenous people rely on forests for food, medicine and cultural needs, and can help protect the forests (Andriansyah et al., 2018).

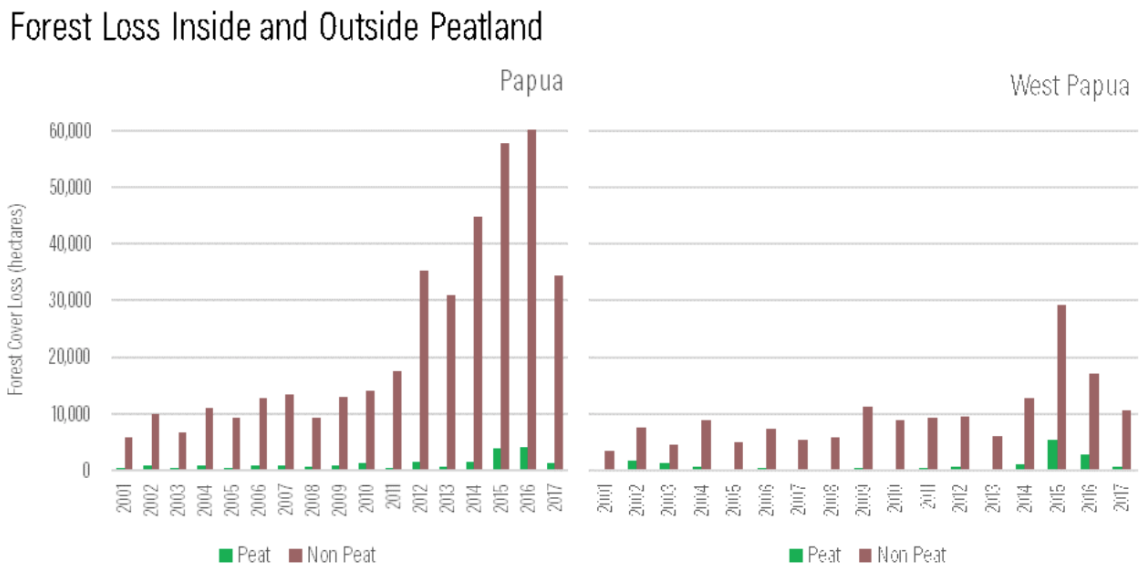
Figure 14 demonstrates forest loss Papua Island in Indonesia, which is home to the majority of Indonesia's primary forests and one of the most biodiverse forests in the world. Although deforestation has begun to decline, it is still at a high level. It is important that peatlands are protected, as they release more carbon. Although deforestation of peatlands is significantly lower than non-peatland, it has the potential to release more carbon making it essential that policies focus on protecting them (see Figure 15 and 16). For example, in West Papua Province, 2015 and 2016 emissions from degraded peatlands contributed about 50-55% more than emissions from forest clearing (Andriansyah et al., 2018).

Figure 14: Forest loss in Papua Island, Indonesia



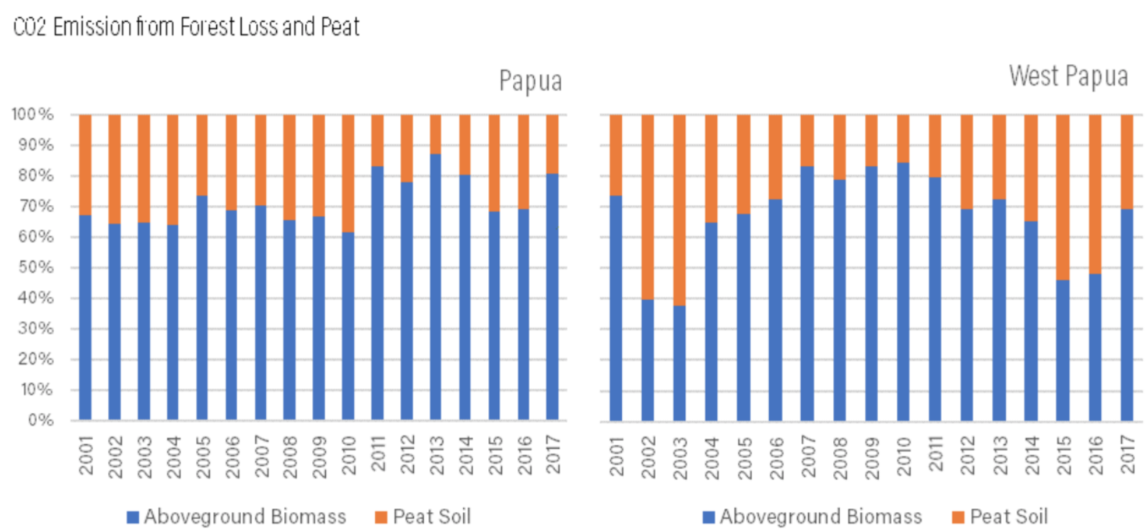
Andriansyah et al., 2018

Figure 15: Forest loss inside and outside peatland



Andriansyah et al., 2018

Figure 16: Carbon emissions from forest loss and soil in peatlands



Andriansyah et al., 2018

In Indonesia over 80,000 trees have been planted as part of an agroforestry project. Indonesian coffee yields are extremely low due to local deforestation. Thus, agroforestry improves ecosystem conditions in fields and ensures the long-term quality and availability of coffee. At the same time it also increases and diversifies revenues for farmers and populations, whilst increasing carbon storage in the soil and through the trees. The agroforestry project focuses on planting fruit trees in and around coffee fields to help preserve soils, reduce erosion, and ensure optimal growing conditions for the production of coffee. It also gives farmers another source of income (timber, fruits, medicinal, animal feed…), thus improving self-sufficiency.[8]

Pakistan

Between 1990 and 2015, Pakistan saw a net loss of over one million hectares of forest, which in turn resulted in a carbon stock loss of over 100 mega tonnes CO2. In Pakistan the demand for forest products (mostly wood fuel) is higher than supply, the population is expanding, grazing is increasing and there is illegal harvesting and land use change, which all drive deforestation. The Climate and Development Knowledge Network (CDKN, 2016) put forward five options to reduce carbon, these are:

- **Community-based forest management:** One-third of Pakistan's forests are community managed, however these suffer from the highest rates of deforestation. It is argued by CDKN that a financial incentive to ensure net increase in carbon storage would enable the community to better manage these forests. It is that community-based forestry management concentrating on carbon sequestration could be implemented in 20% of these forests by 2030.
- **Preservation of conifer forests:** The preservation of conifer forests means complete protection from all harvesting. Despite a ban in place for commercial logging, conifer forests in Pakistan are declining at a rate of around 40,000 ha per year. Preventing this continued decline would preserve a carbon sink and allow additional sequestration through natural regeneration. For the prevention of illegal logging these forests would have to be prioritised for protection.
- **Implement Agroforestry Practices:** Provinces in Pakistan have already begun to run programmes to encourage agroforestry practices, which mainly focus on planting eucalyptus, shisham (rosewood) and kikar. It is possible to plant as much as 12 trees per hectare without having any negative impact on crops, whilst at the same time improving the soil and reducing carbon. However, in order for uptake there needs to be more education on the benefits of agroforestry and how it does not decrease crop yield.
- **Commercial plantations:** Demand for wood products in Pakistan exceed supply and if managed properly commercial plantations can limit carbon. If plantations are well managed the sequestration of carbon compensates for the CO2 emitted by combustion of fuel wood. Timber products such as construction materials, also act as a longer-term carbon sink post-harvest. These forests also reduce pressure on native forests. Additionally, with good forest management, below ground carbon can accumulate despite harvesting of trees.
- **Reforestation of marginal and degraded land:** According to CDKN (2016) deforestation has caused approximately 11 million hectares of land to become degraded in Pakistan. If 10% of this land was reforested it would have the mitigation potential of 2,882,000 tCO2e. Additionally, rangeland degradation and deforestation costs Pakistan roughly US$ 67 million per year and reforestation would reverse some of this degradation

[8] https://www.purprojet.com/project/kopi-lestari/

as well as provide a carbon sink. At the same time, it also provides employment to local communities.

Figure 17 demonstrates the potential reductions and costs of these methods.

Figure 17: Emission mitigation measures and impacts

Emissions Mitigation Measure	GHG Emission Reductions in 2030 ($MtCO_2e$)	GHG Emission Reductions from Sector BAU in 2030 (%)	Marginal Abatement Cost (US$/Tonne CO_2e Reduced)
Community-based forest management	3.2	21.3%	Low (<$25)
Preservation of conifer forest land	4	26.6%	Low (<$25)
Implement Agroforestry Practices*	8.4	56.0%	Very low (<$10)
Commercial plantations	3.2	21.3%	Low (<$25)
Reforestation of degraded land	2.9	19.3%	Low (<$25)
TOTAL FORESTRY SECTOR	**21.7**		Very Low-to-Low

CDKN, 2016: 2

6. References

ABARES. (2011). Abatement potential from reforestation under selected carbon price scenarios. ABARES Special Report. http://carbonpricemodelling.treasury.gov.au/content/consultants_reports/ABARES_Abatement_potential_from_reforestation_under_selected_carbon_price_scenarios.pdf

Andriansyah, M., Firmansyah, R., Wijaya, A., & Chitra, J. (2018). Indonesia's Last Forest Frontier: 3 Facts to Know About Papua. World Resources Institute. https://www.wri.org/blog/2018/11/indonesias-last-forest-frontier-3-facts-know-about-papua

CDKN. (2016). Greenhouse Gas Mitigation Options for Pakistan: Forestry Sector. CDKN Report. https://cdkn.org/wp-content/uploads/2016/10/fact-sheet-Pakistan-Forestry-sector.pdf

Cunningham, S. C., Mac Nally, R., Baker, P. J., Cavagnaro, T. R., Beringer, J., Thomson, J. R., & Thompson, R. M. (2015). Balancing the environmental benefits of reforestation in agricultural regions. *Perspectives in Plant Ecology, Evolution and Systematics, 17*(4), 301-317. doi:https://doi.org/10.1016/j.ppees.2015.06.001

FAO. (2016). Forestry for a low-carbon future: Integrating forests and wood products in climate change strategies. FAO Forestry Paper 177. http://www.fao.org/3/a-i5857e.pdf

Faruqi, S., & Wu, A. (2016). INFOGRAPHIC: 4 Ways to Make Money in Land Restoration. World Resources Institute. https://www.wri.org/blog/2016/12/infographic-4-ways-make-money-land-restoration

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R. T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M. R., Herrero, M., Kiesecker, J., Landis, E., Laestadius, L., Leavitt, S. M., Minnemeyer, S., Polasky, S., Potapov, P., Putz, F. E., Sanderman, J., Silvius, M., Wollenberg, E., … Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(44), 11645-11650. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5676916/

Liu, X., Trogisch, S., He, J.-S., Niklaus, P. A., Bruelheide, H., Tang, Z., . . . Ma, K. (2018). Tree species richness increases ecosystem carbon storage in subtropical forests. *Proceedings of the Royal Society B: Biological Sciences, 285*(1885). doi/10.1098/rspb.2018.1240

Minnemeyer, S., Harris, N., & Payne, O. (2017). Conserving Forests Could Cut Carbon Emissions As Much As Getting Rid of Every Car on Earth. World Resources Institute. https://www.wri.org/blog/2017/11/conserving-forests-could-cut-carbon-emissions-much-getting-rid-every-car-earth

Paterson, S., & Bryan, B. (2012). Food-Carbon Trade-offs between Agriculture and Reforestation Land Uses under Alternate Market-based Policies. *Ecology and Society, 17*(3). Retrieved from http://www.jstor.org/stable/26269072

Torres, A. B., Marchant, R., Lovett, J. C., Smart, J. C. R., & Tipper, R. (2010). Analysis of the carbon sequestration costs of afforestation and reforestation agroforestry practices and the use of cost curves to evaluate their potential for implementation of climate change mitigation. *Ecological Economics, 69*(3), 469-477. doi:https://doi.org/10.1016/j.ecolecon.2009.09.007

Suggested citation

O'Driscoll, D. (2018). *Carbon Abatement Potential of Reforestation.* K4D Helpdesk, Brighton, UK: Institute of Development Studies.

About this report

This report is based on six days of desk-based research. The K4D research helpdesk provides rapid syntheses of a selection of recent relevant literature and international expert thinking in response to specific questions relating to international development. For any enquiries, contact helpdesk@k4d.info.

K4D services are provided by a consortium of leading organisations working in international development, led by the Institute of Development Studies (IDS), with Education Development Trust, Itad, University of Leeds Nuffield Centre for International Health and Development, Liverpool School of Tropical Medicine (LSTM), University of Birmingham International Development Department (IDD) and the University of Manchester Humanitarian and Conflict Response Institute (HCRI).