Mitigating climate change through afforestation/reforestation – Where and how can forests store the most CO_2?

A factsheet by Group 12

Member Club: Linda Schinz, Laura Schnegg, Timo Schneider, Basil Vogelsanger, Gabriel Vollenweider, Matthias Flury

Overall Summary

If climate targets are to be achieved, a clear reduction in CO_2-emissions is needed[1,2]. Regional impacts of climate change can be more pronounced than changes in global averages, further clarifying the urgency to reduce emissions[3]. To have a >50 % chance of limiting global warming below 2 °C, integrated assessment models require large scale deployment of negative emission technologies such as *Bioenergy with Carbon Capture and Storage* (BECCS)[4]. This technology has the potential to lead to a global net removal of CO_2 from the atmosphere, but it comes with risks and challenges in the competitive use of land, water and nutrients such as the harvest intensification of forest for bioenergy, which could reduce future growth and hence the ability of forest to sequester carbon dioxide[4–8].

Tropical forests are considered valuable for mitigating climate change[9–11]. This is due to their large evapotranspiration rate and cloud formation[9,10,12] as well as the sequestration of carbon into plant biomass[10]. In tropical environments, it was observed that mangrove ecosystems store by far the most carbon (830–1218 Mg C/ha), followed by upland forests (375–437 Mg C/ha), and savannas which store the least (156–203 Mg C/ha)[13]. Outside the tropics, it was found that temperate forests store more carbon (199–550 Mg C/ha) than boreal forests (129–434 Mg C/ha)[14,15]. However, the benefit of afforestation in temperate climates is still uncertain[11]. And in boreal regions, the cooling effect of carbon sequestration by afforestation is weakened since forests absorb more radiation than snow-covered, non-forested areas[9–12].

Another factor that needs to be taken into account is that future afforested or reforested forests will be impacted by climate change and that the effect of climate change on forests is latitude-dependent[16,17]. On the one hand, climate change will have a negative impact on tree growth in tropical forests[16]. Carbon sequestration is reduced by increased heat stress[16] and decreased precipitation[17]. On the other hand, Mediterranean and boreal forests are generally positively impacted (increased tree growth)[16].

Additionally, climate change can lead to more forest fires which reduce the carbon storage of forests[17]. They can also lead to degradation, which in turn leads to substantial carbon emissions[18]. Degenerated forests will have higher fire intensities than healthy forests[19,20].

The carbon storage capacity of an ecosystem is also influenced by many other factors, including: environmental conditions, slope angle and orientation, life history, tree morphology, disturbances, and land-use history[14,21]. Natural or selectively used forests provide a greater potential for long-term carbon storage in the soil organic layer than intensively managed forest plantations with short rotation periods[22]. Above-ground carbon storage is significantly higher for restoration forests than for monocultures and mixed species plantations[23].

In summary, tropical regions and especially mangrove forests seem to be valuable for capturing CO_2[13]. The reason for this is the reduced decomposition of organic matter in these areas[24]. The carbon is stored in the sediments of the mangrove forests[24]. Other factors which influence the carbon storage capacity are how intensively the forest is used[14,21]. These should be considered as well when re- or afforesting. Future afforested forests will be affected by climate change and the effect will be latitude-dependent[16,17]. Climate change causes more forest degradation, and this leads to more carbon emissions[18].

Partial research A: recent CO_2-evolution and the role of forests in climate change

Gabriel Vollenweider

Summary

In recent years, the main emitters of CO_2 were emerging economies (China, India) and the USA[1]. Emissions are rising quickly because GDP is growing, and decarbonisation is slower than expected (growth in international trade). A clear reduction in emissions is needed to achieve climate targets[1,2]. In order to limit warming below 2 °C, negative emissions are needed (e.g. carbon capture and storage)[1]. The urgency of reduced emissions is clarified through regional impacts. Often, these are more pronounced than changes in global averages[3].

The effect of climate change on forests is region-dependent[16,17]. Tropical and subtropical forests are negatively impacted (heat stress). Mediterranean and boreal forests are positively impacted (initially colder climate is warming). As a consequence, forests might migrate northwards[16]. Climate change can also lead to more forest fires. These reduce the species diversity and the density of seedlings, impairing the regenerative capacity of forests[17].

Trends in the sources and sinks of carbon dioxide[2]

- emission sources: fossil fuels and cement / land-use change (deforestation)
- emission-growth mainly due to emerging economies (developing countries)
    - growth in international trade (more exports to developed countries)
- overall, sinks can’t seem to keep up with growing emissions
    - likely due to climate variability and climate change
    - need to reduce emissions (decarbonisation of ever-growing GDP)

Persistent growth of CO_2 emissions and implications for reaching climate targets[1]

- emissions from fossil fuel and cement are linked to GDP and carbon intensity (carbonisation)
    - recently, GDP is growing a bit slower, and carbon intensity is decreasing a bit faster
- GDP-based projections of emissions are higher than all 2 °C scenarios in the literature
    - many 2 °C scenarios are unfeasible without negative emissions (BECCS, CCS, CDR)
    - slower decarbonisation than IPCC 2 °C scenarios (mainly due to emerging economies)
    - clear break in emission-trends is needed for achieving 2 °C target

Allowable CO_2 emissions based on regional and impact-related climate targets[3]

- over most land areas, expected local changes are much larger than global changes
    - reasons: land-sea contrast in radiative forcing, feedbacks (less moisture, less snow)

- the hottest day of the year is projected to become hotter more quickly than the trend in global mean temperature
- in the Arctic, the coldest night of the year is projected to get hotter at an even higher rate
- heavy precipitation events are projected to occur more often with higher global temperature
- the link between local changes and global mean temperature can be combined with the link between global mean temperature and CO_2 emissions

Probing for the influence of atmospheric CO_2 and climate change on forest ecosystems across biomes[16]

- the effect of increasing atmospheric CO_2 on tree growth is latitude-dependent
- in the tropics and the subtropics, tree growth is decreasing
    - in warmer climates, rising temperatures lead to reduced photosynthesis (heat stress)
    - this effect outweighs the higher CO_2-availability
- in the temperate regions, tree growth is decreasing more often than not
- in mediterranean and boreal forests, rising temperatures and higher CO_2-availability stimulate growth
    - this might lead to northwards migration of forests due to climate change
- generally, tree growth in forests will not compensate CO_2 emissions

An overview of interrelationship between climate change and forests[17]

- deforestation accounts for 20% of total greenhouse gas emissions
    - deforestation carbon emissions were approximately constant over the last 20 years
    - subsequent climate change can impact forest health, potentially leading to further deforestation
- climate change affects tropical forests more than temperate and mediterranean forests
- tree growth is strongly influenced by water availability (precipitation) and temperature
    - less precipitation and higher temperatures cause some species to migrate towards higher elevations
- climate change can increase the potential for forest fires, which reduces carbon storage, regenerative capacity, and species diversity of forests
- climate change can both decrease and increase forest carbon storage (regional variability)

Partial research B: In which regions is aff-/reforestation effective and why?

Linda Schinz

Summary

Tropical forests are considered valuable for the storage of carbon and mitigating climate warming. This is justified with the large evapotranspiration and cloud formation and the sequestration of carbon into plant biomass. The boreal regions are found to be less suitable for afforestation, since forest has a lower albedo than snow-covered, non-forested areas and therefore offset some of the negative radiative forcing due to carbon sequestration. There is still uncertainty about the benefit of afforestation in temperate regions.

Biophysical considerations in forestry for climate protection[10]

Review of published and emerging research; Accumulation in living biomass is highest in tropical forests and decreases towards the poles; Accumulation in SOC is greatest in clayey soils, croplands and cooler climates (slower decomposition losses) and with certain tree species; tropical forestry likely has greatest climate benefits (high C storage and uptake, coverage of land large, highest net cooling (transpiration and cloud formation)); Boreal forests reduce surface albedo and increase surface roughness; Net effect of afforestation in mid-latitude regions may be negligible; Urban forests can provide local cooling

Biogeophysical effects of land use on climate: Model simulations of radiative forcing and large-scale temperature change[12]

Analysis with a model; Focus on radiative forcing, not on C sequestration; Deforestation in the 20th century in northern mid-latitude resulted in a cooling due to increased surface albedo; In cold regions, afforestation/reforestation would exert a positive radiative forcing and thus offset the negative forcing due to carbon sequestration; Tropical regions: a double cooling effect through sequestration and increased evaporation and cloud cover; conclusion: Carbon accounting alone can give a false impression of the potential for forest plantations to mitigate climate warming;

Forests and climate change: Forcings, feedbacks, and the climate benefits of forests[9]

Review of biosphere-atmosphere interactions in tropical, temperate and boreal forests; Tropical forests: Net balance among the processes is mitigation of global warming through evaporative cooling and carbon sequestration; Boreal forests: Model simulations show that the low surface albedo of forests warms the climate compared to the absence of trees; Boreal forests have low annual carbon gain but are large stores of C in soil, permafrost and wetland; The climate forcing from increased albedo may offset the forcing from carbon emission so that boreal deforestation cools climate; Temperate forests: Croplands have higher albedo than forests and many models show that trees warm surface air temperature relative to crops;

Protecting climate with forests[11]

Tropical forests provide greatest value because carbon storage and biophysics align to cool the Earth; In boreal regions, carbon storage is counteracted by smaller albedo of forests; Rates of carbon storage in boreal forests are much lower (colder temperatures, less sunlight); Planting forests in northern countries will help stabilize global atmospheric CO_2 but may accelerate climate warming regionally, further speeding the loss of snow and ice cover; Temperate forests: Greatest uncertainties – conflicting study results (water availability plays an important role);

Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation[25]

Clean development mechanism = instrument of the Kyoto Protocol that includes afforestation and reforestation; Paper studies land suitability for CDM-AR; 46% of suitable areas were found in South America, 27% in Sub-Saharan Africa. Most land was shrubland/grassland or savanna (low population density); In Asia, less land was available; Globally, more than 760 Mha land were found suitable for CDM-A; The estimates should be considered a theoretical potential for CDM-AR, as the conversion into forest is dependent on socio-economic and local food security issues; lands identified as suitable for CDM-AR generally fall into low to moderate productivity regions;

Partial research C: Influence of vegetation types on carbon storage in reforestation projects

Basil Vogelsanger

Summary

Different factors including environmental conditions, life history, tree morphology, disturbances and land-use history influence an ecosystem's carbon storage capacity[14]. These factors lead to the fact that temperate forests store more carbon than boreal forests[14,15]. In tropical environments, mangrove ecosystems store by far the most carbon, followed by upland forests, savannas store the least[13]. Slope angle and orientation can have a significant influence on the forest's carbon storage capacity, north-facing forests seem to store more carbon[21]. The above-ground carbon Storage is significantly higher for restoration forest than monocultures and mixed species plantations[23].

Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests[14]

Highest biomass carbon density can be found in Australian temperate moist Eucalyptus regnans forests (1,867 tonnes carbon per ha); old-growth forests seem to be useful carbon sinks; temperate moist forests have higher biomass carbon densities than boreal and tropical forests; Factors influencing biomass carbon density include environmental conditions, life history and morphological characteristics of tree species, natural disturbance, and land-use history; Age of trees influences carbon storage

Variation in carbon stocks on different slope aspects in seven major forest types of temperate region of Garhwal Himalaya, India[21]

The study focuses on temperate forests; Slope angle and orientation can have an impact on C storage capacity; more soil organic carbon is stored in north-facing forests (probably only accounts for that region), could be because of moister and cooler climate on northern aspects and harsher environments on the southern because of wind and wildfires, etc.; total tree carbon density is also on north-facing slopes higher

Whole-island carbon stocks in the tropical Pacific: Implications for mangrove conservation and upland restoration[13]

Study on carbon storage of tropical island ecosystems especially on mangroves; Mangroves stored the most carbon (830-1218 Mg C/ha), Savannas (156-203 Mg C/ha) contained significantly lower C stocks than upland forests (375-437 Mg C/ha); conservation and management of C rich mangrove forests is of high importance; mangrove ecosystems have C rich soils; a transition from savannas to forest ecosystems could maximize carbon storage

Carbon stocks in above-ground biomass of monoculture plantations, mixed species plantations and environmental restoration plantings in north-east Australia[23]

Significantly higher above-ground C storage for restoration forest than monocultures and mixed specie plantations; three reasons account for this: higher stock, higher average tree diameters and higher wood density in restoration forests; C storage with monocultures is more cost-effective; reforested forest (average 14 yrs. old) stores 80% of primary forests; highest C accumulation in the first 20 yrs. after reforestation

Variation in Carbon Storage and Its Distribution by Stand Age and Forest Type in Boreal and Temperate Forests in Northeastern China[15]

The study is on boreal and temperate forests in China; Higher C storage in Temperate (198.9–549.8 Mg C/ha) than in boreal (128.6– 434.0 Mg C/ha) forests and higher C storage in old stands; C in tree biomass is the largest component and is influenced by forest type, forest zone and stand age; C storage in soil is the second largest component; cool climate and moderate precipitation seem to favour high biomass C accumulation; higher plant diversity in temperate ecosystems could be the reason for higher C storage; Forest floor C is higher in boreal forests, possibly due to lower temperature; forest age is not correlated with soil C storage

Partial Research D: How does afforestation influence the fire management of an area threatened by forest fire and why should energy wood be avoided?

Laura Schnegg

Summary

Avoiding forest fires also means avoiding carbon emissions[18–20,26]. However, wildfires are also important for the ecosystem[20]. Forest fires cannot and should not be completely avoided[18,19]. To keep the consequences within limits, a fire management concept is necessary[18–20]. Fire management is integrated in the concept of REDD+, which means Reducing Emissions from Deforestation and Degradation[19]. The aim of this concept is to reduce greenhouse gas emissions policy approaches and positive incentives[19]. Five activities are involved: *"reducing emissions from deforestation, reducing emissions from forested degradation, sustainable management of forests, conservation of (existing) forest carbon stocks and enhancement of forest carbon stocks (e.g. through regeneration and planting in previously forest land)"*[19]. Degenerated forests will have higher fire intensities than healthy forests[18,26,27].

Carbon, Fossil Fuel and Biodiversity Mitigation with Wood and Forests[27]

main focus on wood products and their capability as a CO_2 sink, sustainable yield calculation for optimizing CO_2 saving of a forest and thus avoid catastrophic wood fires, importance to preserve structure of forest by natural events or by harvesting

Forest degradation promotes fire during drought in moist tropical forest of Ghana[18]

fires can lead to degradation → turn leads to substantial carbon emissions, active fire management for preventing ongoing forest degradation and strengthen forest against climate change

The critical importance of considering fire in REDD+ programs[19]

REDD+ → reducing emission from deforestation and degradation, aim is to reduce greenhouse gas emissions by policy approaches and positive incentives, forest fires by agriculture/logging/drought are not involved in REDD+ program but have an important impact on forest, forest degenerated by logging or repeated fires -> increasing of fire intensity for future events, accumulation of downed woody material works as fuel, less moister due to an more open canopy, evidence that suggest fire (Zuckerrohrbrände) reduces forest biomass → large tree mortality, effect on carbon accumulation rate of the forest, avoiding repeated fires is important, reaching by a well-managed logging

Fire in Protected Areas-the Effect of Protection and Importance of Fire Management[20]

analysing importance of wildfire for ecosystem in protected areas, different aspects on fire management, two ways → (1.) main focus on suppression strategies (fire used to stop the fire, mainly used by locals), (2.) prevention strategies (artificial fires started by humans used to prevent other fires), accumulation of biomass in the last 50 years because of land-use change It also describes how land-use change, increases possibility for wildfires

The carbon footprint of traditional woodfuels[26]

non-sustainable harvest pushes forest degradation/deforestation/climate change, sustainable process means harvesting area below the annual growth rate (biomass needs time to regrow), wood fuel dependent regions have high rates of deforestation and higher wood fuel emissions, reducing them by more modern cook stoves

Greenhouse Gas and Carbon Balances in Mangrove Coastal Ecosystems[24]

mangroves are good carbon stores, carbon is stored in the sediments, carbon comes from the biomass of the mangroves, biomass is poorly decomposed, Reason: tides, which prevent a permanent oxygen supply

Partial Research E: What are potential risks and chances of bioenergy and carbon capture?

Timo Schneider

Summary

To have a >50% chance of limiting global warming below 2 degrees, integrated assessment models require large scale deployment of negative emission technologies such as BECCS. This technology has the potential to lead to a global net removal of CO_2 from the atmosphere, but it comes with risks and challenges in the competitive use of land, water and nutrients[28]. A median BECCS deployment of around 3.3 Gt C yr^{-1} is needed to meet the 2 degrees target. This implicates the question, whether these rates of deployments can be achieved and sustained. Economic and biophysical limits also interact with societal challenges such as water, food and energy security. Further research as well as the development of socio-economic governance systems are needed to enhance the understanding of potential risks/improvements and to provide incentives for R&D, to overall limit the adverse impacts of a transition to low-carbon energy systems.

Bioenergy as climate change mitigation option within a 2 °C target uncertainties and temporal challenges of bioenergy systems[5]

This study analyses challenges for bioenergy systems to contribute to the emission reduction targets for a global 450ppm CO_2 stabilization. National and international policies can help to develop sustainability standards with emission thresholds related to the cumulative emission budget. Local policies and business decision should address more case and context specific aspects of bioenergy systems along the full supply chain. There still remains a reasonable uncertainty in standardized emission evaluation methods as they are based on assumptions and cannot guarantee to produce harmonized and comparable results for the same bioenergy system.

Can BECCS deliver sustainable and resource efficient negative emissions[6]?

This study analyses the BECCS value chain and evaluates the water, carbon and energy footprints, considering sourcing the biomass from different regions, climates and land types. Results show that the BECCS technology could lead both to carbon positive and negative results, depending on the conditions of its deployment. The most important contributors to embodied energy were biomass transport for low moisture biomass, and transport, chemical input and processing for high moisture biomass. BECCS carbon intensity per hectare could vary greatly in the amount of resource use to remove a ton of CO_2 from the atmosphere there for a minimum CO_2 removal efficiency could be of great value to differentiate between efficient and inefficient systems.

Mitigation potential and environmental impact of centralized versus distributed BECCS with domestic biomass production in Great Britain[7]

This study analyses two plausible bioenergy production pathways for bioenergy with carbon capture and storage based on centralized and distributed energy systems. To meet the Carbon Budget target, it would be necessary to produce solid biomass from forest systems on an additional 0.49-0.59 Mha or to import 6.6Mt/year for the centralized or distributed energy system. The goal of 50 Megatons CO_2 equivalent per year could only be achieved by converting around 1 Mha of agricultural land to bio-energy crop production but 0.5 Mha of it would be good grade agriculture land that carries the risk of displacing food production.

Preconditions for bioenergy with carbon capture and storage (BECCS) in sub-Saharan Africa: the case of Tanzania[8]

Most mitigations scenarios below global warming of two degrees include some kind of negative emissions technologies, with BECCS reporting the greatest mitigation potential. Basically, Sub Saharan Africa is attractive for the use of BECCS technology because of large areas that could contribute to biomass energy and to underground CO_2 storage. Preconditions for the application of BECCS systems are namely the domestic sugarcane-based energy production with Tanzania as a producer in an international BECCS chain, supplying biomass or biofuel for developed countries.

Biophysical and economic limits to negative CO_2 emissions[28]

For scenarios that are consistent with the <2 degrees global warming target, models estimate that a median BECCS deployment of around 3.3 Gt C yr^{-1} is needed. This implicates the question, whether these rates of deployments can be achieved and sustained. Related investments are estimated to grow up to US$ 138.3 billion and 122.6 billion yr^{-1} by 2050 to achieve the levels of implementation compatible with a 2 degrees target. In addition to economic resources, the deployment of BECCS can be limited by the competition for land, by nutrient demand and by increased water use. These limits interact with societal challenges facing humanity in the coming decades such as water, food and energy security and could limit the implementation of BECCS. Early deployment of BECCS in for example pilot studies could enhance the understanding of the risks and possible improvements. A heavy reliance on BECCS, if used as a measure to allow continuing use of fossil fuels is extremely risky as our ability to stabilize the climate declines with the increase of cumulative emissions. Implementing BECCS to meet the <2 degrees target will have significant impact on either land, energy, water, nutrient or costs and therefor a failure to meet the expected mitigation due to mentioned biophysical and economic limits, is a possibility.

Partial Research F: Why is it important, in relation to forests as CO_2 reservoirs, to not only aff-/reforest, but primarily to avoid the conversion of forest? What are the reasons for deforestation?

Matthias Flury

Summary

Natural grown forests (primary or secondary) have higher carbon sequestration rates and stock than forest plantations[4]. Studies suggest that old primary forests as well as Korean pine plantations function as carbon (C) sinks, while 60y-old secondary forest are only small C sinks or main C sources[29].

Natural or selectively used forests provide a greater potential for long-term carbon storage in the soil organic layer than intensively managed forest plantations with short rotation periods[22].

While afforestation of cropland leads to a soil organic carbon (SOC) accumulation, the afforestation of grasslands does not[30].

While proximate causes of deforestation (in Malawi) are agricultural expansion and the use of wood for brick burning, cooking and building of tobacco barns, the underlying causes are poverty, population growth, expensive alternate building materials and lack of awareness, commitment and ressources[31].

Ecosystem Carbon Stock Influenced by Plantation Practice: Implications for Planting Forests as a Measure of Climate change mitigation[4]

This Meta-study shows that natural (primary or secondary) forest has higher C sequestration rates and C stocks than forest plantations. In comparison with natural forests, plantations decreased aboveground net primary production by 11%, soil C concentration by 32%, and soil microbial C concentration by 29% in plantations relative to natural forests. The results are consistent over various factors, such as stand age, types, study regions, land-use history, etc.

The paper argues that current strategies concerning C sequestration through creating plantations should be adjusted by governments.

Effects on Carbon Sources and Sinks from Conversion of Over-Mature Forest to Major Secondary Forests and Korean Pine Plantation in Northeast China[29]

This study measured the fluxes of CH4 and CO_2 in soils and the annual C sequestration of 7 Ecosystems (over-mature forest (OMF), Korean pine plantation (KPP), and fife secondary forests).

SOC was significantly higher in OMF (30.3%) compared to KPP. SOC in OMF was higher than in 4 of the secondary forests, but only significantly for two of them.

The secondary forest did have significantly higher negative CH_4 Emissions than OMF and KPP.

No significant difference was observed between CO_2 flux of OMF and KPP (KPP was higher than OMF by 16.4%, $p > 0.05$). The secondary forest types did have higher CO_2 emissions than both OMF and KPP.

The annual net C sequestration in vegetation was significantly greater in KPP than in OMF and secondary forests.

OMF acted as a C sink ecosystem, accumulating 1.15 t ha^{-1} y^{-1}. The 51-year-old KPP acted as a strong C sink absorbing 2.54 t ha^{-1} y^{-1}. Among the five secondary forests converted from over-mature forests 60–66 years ago, one acted as a small C sink while the other four secondary forests acted as C sources.

Carbon stocks and soil respiration rates during deforestation, grassland use and subsequent Norway spruce afforestation in the Southern Alps, Italy[22]

Human impacts as well as erosion after deforestation resulted in the loss of the old A_0 soil horizon that had developed during forest growth. The total carbon loss attributable to deforestation was 272 Mg C ha^{-1}.

After afforestation a linear increase in soil carbon stocks in the organic layer at a rate of 0.36 Mg C ha^{-1} $year^{-1}$ occurred. Carbon accumulation in stem biomass rises exponentially (thus young trees accumulate less than mid-aged trees (30-60y)), but slows down after 60-80 years.

Natural or selectively used forests provide a greater potential for long-term carbon storage in the soil organic layer than intensively managed forest plantations with short rotation periods.

Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe[30]

Afforestation of Cropland leads to a SOC accumulation of 21 ± 13 Mg ha^{-1}. 91% of the C stock change occurs in the topsoil (depth 0-30cm). The forest floor accounts for 12% of total SOC accumulation.

The conversion of grassland to forest leads to a slight non-significant decline in total SOC stocks in the mineral soil (− 10±7 Mg ha−1), which was partly offset by the mean accumulation of SOC in the forest floor.

Root turnover in grasslands is higher due to regular aboveground biomass loss through harvest. This may explain higher SOC accumulation compared to afforestation.

An Analysis of the Causes of Deforestation in Malawi: A Case of Mwazisi[31]

Proximate factors for deforestation are agricultural expansion, growing of Tobacco (as a cash crop) and excessive use of biomass for cooking and brick burning.

Underlying factors for agricultural expansion are population growth and poverty (>no purchase of farm inputs (e.g. fertilizers) to improve fertility).

Underlying factors for deforestation because of growing of tobacco are lack of commitment, market dynamics and low level of awareness (regarding forest use and management).

Underlying factors for deforestation for brick burning are poverty, expensive alternate building materials, a lack of resources and awareness.

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