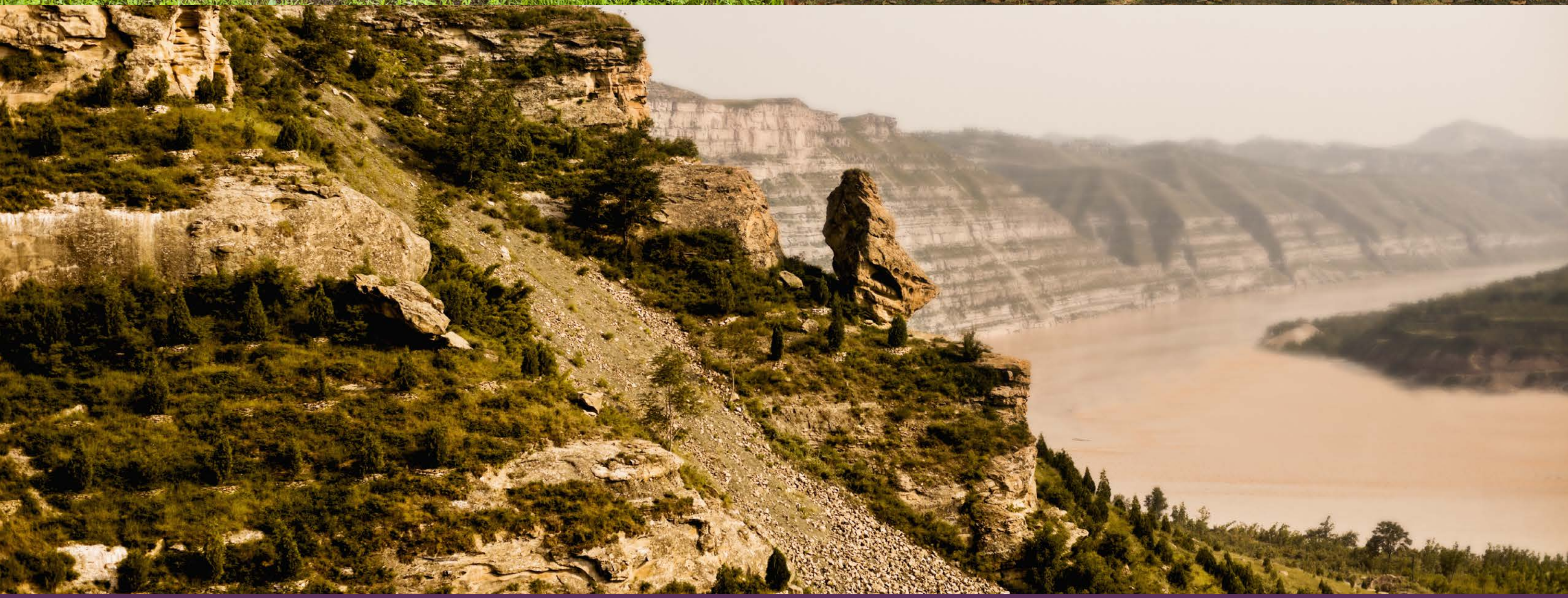
# LARGE-SCALE FORESTATION FOR CLIMATE MITIGATION

Lessons from South Korea, China, and India



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# Large-scale Forestation for Climate Mitigation: Lessons from South Korea, China, and India

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# Executive Summary

This study was commissioned to assess long-term experiences with several major, government-led forestation efforts, and to draw lessons from those experiences that could inform decisionmakers about what it takes for such efforts to provide substantial, measurable contributions to climate change mitigation. The afforestation, reforestation and forest restoration (A/R/R) programs undertaken by China, India, and South Korea – the subjects of this study – achieved more than 12 $GtCO_2$ of carbon removals over the past two decades. These large, sustained governmental A/R/R programs provide evidence for the scale of carbon removals that are achievable through active interventions centered on tree planting and maintenance, and for what is required to achieve such significant results.

In all three cases, **an effective institutional framework was a necessary condition of success,** including multilevel and interministerial coordination, and **successful A/R/R programs were closely interwoven with rural economic development**. Additionally, in South Korea and China high-profile, **acute crises were drivers of political action** by central governments.

In all three cases **governments invested heavily.** South Korea spent more than 1% of its total national budget (about USD 200 million per year) during its peak A/R/R. China and India have both invested over USD 10 billion per year recently. Cost per hectare was as low as USD 30-74 early on in India, up to USD 2151-2317 recently in China. Rough estimates of cost per ton of $CO_2$ sequestration range from a low of USD 1.00 in India to USD 25.60 per ton in China.

This research also identified several lessons across the case studies related to goal-setting, reporting and information needed to support the success of A/R/R for climate mitigation. First, **there is a consistent and large difference between reported afforestation and reforestation areas and observed changes in forest cover**, with 2.5 to 7.5 times as much A/R area as forest expansion across the three cases.

Second, **forest area trends alone provide a poor measure of A/R/R success and mitigation.** Alternative measures such as forest volume, stocking rate, and carbon density are better indicators that A/R/R actions have achieved carbon impacts. For example, forest area in South Korea has been declining while carbon sinks continue to grow.

Third, **there is a lack of reporting on forestation efforts that rely on natural regeneration**. These "non-A/R/R" efforts, such as enclosing hillsides or paying farmers to abandon unproductive lands to allow forests to regenerate, may have substantial potential.

Fourth, **consistent and effective monitoring is critical for both adaptive management and assessment of A/R/R efforts and outcomes**. The information provided by China's and India's National Forest Inventories to policymakers and South Korea's external monitoring of restoration areas provide examples of the type of information critical to understanding the success of A/R/R efforts.

Taken together, these lessons suggest that **A/R/R goals in a climate context should be outcome-based rather than input-based**, and linked directly to the forest carbon statistics that countries tracks in national forest inventories and use for compiling GHG inventories. Doing so will provide the data necessary to develop climate positive policies, and provide the international community with the information needed to understand the contribution of A/R/R towards Paris Agreement goals.

# Contents



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# Introduction

The world agreed to balance anthropogenic climate emission sources and sinks in the latter half of the century at the 21st Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015 in Paris. The goal shines a spotlight on forest sinks and has reinvigorated interest in large-scale afforestation, reforestation and forest restoration (A/R/R, see following pages for definitions) as the only existing "geo-engineering" options for sequestering carbon from the atmosphere that avoid the potential for large unintended consequences.

This study explores the empirical basis for large-scale, government-led A/R/R efforts to be an effective climate mitigation strategy. It does this through a close examination of historical forestation programs undertaken by South Korea, China, and India[1] to better understand the scale and success such efforts, including how they impact national-scale forest area, stock, and emissions statistics. These three countries were chosen because: a) their forest rehabilitation efforts were national in scope, allowing for comparison with national-level GHG emissions inventories and estimates; b) A/R/R efforts were government-led and intentional; c) any observed forest recovery could be attributed largely to A/R/R programs, rather than resulting largely from rural-to-urban migration or to concurrent economic development; and d) government sources and independent literature provide sufficient data on the extent of A/R/R efforts and on forest and land emissions and removals.

We examine in some detail the motivations, enabling conditions, and implementation of A/R/R actions that were undertaken – not to try to extract broad cross-cutting lessons about success factors for forest landscape restoration (which has been done quite well by others with a much broader set of case studies) – but rather in recognition that some of the same factors likely mediate the resulting forest area and carbon impacts, and may be important in drawing lessons from these case studies for a broader A/R/R mitigation effort. Along the way, we also seek to identify information and data gaps that hinder such assessment, and extract additional recommendations in this area to inform future monitoring of forestation programs.

Through a close examination of these three country case studies, the following questions are addressed:

- How much forest expansion and climate mitigation has been achieved through large-scale ARR efforts? At what cost?
- How successful have large-scale A/R/R efforts actually been as mitigation tools?
- Are there information and reporting gaps that hinder assessment of ARR's potential role in climate mitigation?

It is important to note that none of the three case study countries' A/R/R programs were intended primarily as a GHG mitigation strategy, which suggests some caution in extrapolating the lessons learned to mitigation efforts. However, this paper concludes with a view on whether the evidence suggests that ARR should be a major focus of climate mitigation efforts. It also offers insights learned about the conditions under which large-scale tree planting can achieve positive carbon outcomes. And finally, it identifies several lessons on goal-setting, reporting and information needed to supporting the success of future A/R/R efforts for climate mitigation purposes.

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[1] There have of course been other examples of A/R/R efforts and success in other countries. Especially notable are the turnaround in forest cover and health in Costa Rica, and the impact of land- and tree-tenure devolution as exemplified by Niger's experience in the Maradi and Zinder regions. Countries were selected for this study because of their scale and because their reversals in forest loss have been attributed at least in part to intentional A/R/R actions.

## Defining Afforestation, Reforestation and Restoration[2]

These terms are defined differently depending on context. Below are the definitions used in this paper unless otherwise noted, along with their definitions in the context of the FAO, as it is an important data source for the case studies, and the UNFCCC, as the key context for global climate mitigation efforts.

Afforestation: *Establishment of forest through planting, seeding and/or the human-induced promotion of natural seed sources*[3] *on land that was not recently classified as forest.*

- The FAO defines "afforestation" as "establishment of forest through planting and/or deliberate seeding on land that, until then, was not defined as forest." It is one of two mutually exclusive subsets of "forest expansion," defined as "expansion of forest on land that, until then, was not defined as forest." Afforestation is contrasted with "natural expansion of forest," the "expansion of forest through natural succession on land that, until then, was under another land use (e.g. forest succession on land previously used for agriculture)." It is noted that both "afforestation" and "natural expansion of forest" imply a transformation of land use from non-forest to forest.
- In the UNFCCC context, afforestation is defined as "the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources."
- The FAO and UNFCCC definitions are compatible in the sense that they require human action, crossing of the forest/non-forest threshold and ceasing of other predominant land uses.
- This paper's definition is a combination of the FAO and UNFCCC definitions, but intended to be applicable across forest definitions.

Reforestation: *Re-establishment of canopy cover sufficient to meet biophysical forest thresholds through planting, seeding, and/or the human-induced promotion of natural seed sources, on land currently or recently classified as forest, below forest thresholds, and with no intervening land use.*

- Biophysical forest thresholds usually include minimum canopy cover, height, and/or areal extent. For example, the FAO forest definition includes "land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*."
- The FAO defines reforestation as "Re-establishment of forest through planting and/or deliberate seeding on land classified as forest." It further notes that "reforestation": "1) implies no change of land use; 2) includes planting/seeding of temporarily unstocked forest areas as well as planting/seeding of areas with forest cover; 3) includes coppice from trees that were originally planted or seeded; and 4) excludes natural regeneration of forest."
- In the UNFCCC, "reforestation" is defined as "the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land." Under the Kyoto Protocol, the definition also includes a cut-off date: "For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989."

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[2] FAO definitions and quoted content are from: FAO (2012). Forest Resources Assessment Working Paper 180. FRA 2015 Terms and Definitions. Rome, 2012. Available at: http://www.fao.org/docrep/017/ap862e/ap862e00.pdf. UNFCCC/KP definitions are from FCCC/CP/2001/13/Add.1, as cited in the IPCC's Good Practice Guidance for Land Use, Land-Use Change and Forestry (2003). An in-depth (although slightly out-of-date) analysis of definitional differences and issues between FAO, UNFCCC, and other contexts is available at http://www.fao.org/docrep/005/Y4171E/Y4171E10.htm

[3] An example of "human-induced promotion of natural seed sources" would be assisted succession, in which competing species (often invasive) are removed that would otherwise prevent successful establishment of trees, allowing forests to return without planting or seeding.

- The FAO and the UNFCCC definitions of reforestation are incompatible with each other – FAO reforestation takes place in areas already under a forest land use (in contrast to afforestation, which is a change in land use), while UNFCCC reforestation is of areas under non-forest land use (contrasted with afforestation only in the time span of an intervening land use).
- The definition of "reforestation" in this paper is more limited than the FAO's, by excluding re-establishment of canopy cover on areas that already exceed biophysical thresholds of forest.

{Forest} Restoration: *Planting, seeding, human-induced promotion of natural seed sources, and/or other treatments intended to enhance canopy cover and/or carbon stocks on land classified as forest and exceeding biophysical forest thresholds.*

- The term "forest restoration" is imprecise and difficult to define in a way that captures the wide range of common usage in the literature.[4]
- In the context of carbon mitigation, "forest restoration" may be usefully defined to be symmetric with (i.e., the opposite process as) forest degradation, although the definition of forest degradation under the UNFCCC remains an active area of work.[5]
- The definition used here is somewhat broader than the concept of "enhancement of carbon stocks" defined under the UNFCCC by including enhancement of canopy cover.
- This definition is more narrow than many, as actions intended to enhance a broader range of forest ecosystem function than just carbon stock or canopy cover are often included.

As defined above, the three terms are intended to be mutually exclusive and collectively exhaustive, covering the range of human actions to increase tree cover and carbon content of land that is forest after the actions are complete, and excluding "inaction" that relies on natural regeneration. These definitions maintain a distinction between afforestation and reforestation based on the presence or absence of intervening land use, similar to the FAO approach rather than the UNFCCC approach based on the timespan of a necessary intervening land use. Eliminating definitional overlap between "reforestation" and "restoration" means that reforestation reported to the FAO will be referenced in this paper as "reforestation and restoration" ("R/R"), as there is no way to divide it into planting of land below biophysical forest thresholds (herein, "reforestation"), versus planting of land above such thresholds (herein, "restoration," but included as "reforestation" in FAO reporting).

The terms "forest" and "classified as forest" in the definitions above are not intended to be specific to a canopy cover or combined cover/land use definition of forest. The meaning of the three key terms is thus context dependent. For example, planting trees in a formerly forested area with zero tree canopy cover and no intervening land use is considered "reforestation" in South Korea, which uses a land use definition of forest and thus would classify the area as forest both before and after the action; while the same action on the same land would be considered "afforestation" in China, which uses a canopy cover definition of forest and where land with zero tree canopy would not be classified as forest prior to the intervention. Because of the context-dependence of these definitions, the collective term "afforestation, reforestation, and/or restoration" – abbreviated "A/R/R" – is used when the context is broader than a single country. "Forestation" is used as a synonym for "A/R/R."

[4] Stanturf, John A. 2005. What is forest restoration?. Restoration of boreal and temperate forests, CRC Press, Boca Raton.
[5] See, e.g., http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/degradation_contents.html

# The Republic of Korea: Bringing Forests Back from the Brink

The overall health of Korea's forests declined significantly in the first half of the 20th century, even though very little forest area was converted to other land uses. Decades of timber extraction including during the Japanese Colonial Era in the early 20th century and the 1950-1953 Korean War decimated most of South Korea's forests. Post-war firewood demand for heating and cooking quickly degraded remaining forest areas. Perhaps surprisingly, forest area defined by land use and land registration (and not by the amount of trees on such land) was very stable during this period – recording only a slight decline from 6.9 million hectares in the late 1920s (the earliest reliable data) to 6.8 million hectares in the mid-1950s (a pattern of slow decline that has continued until today).[6] However, *stocked* forest area—defined as a forest area of at least 1 hectare and 30% tree cover[7]—shows a very different pattern. By the mid-1950s, stocked forest area had declined from pre-war levels of about 5 million hectares (52% of national land area) to only 3.4 million hectares (35%).[8] The remaining stocked forest area was severely degraded as well with stocking levels of 10-30 $m^3$ per hectare,[9] a mere 36-40% of the pre-war levels.[10]

South Korea experienced a post-war decade of extreme social chaos and poverty from the early-1950s to the early-1960s, with pressures on forests changing in form but remaining unsustainable. Large-scale organized timber extraction generally ceased, and many previously clear-cut areas grew to exceed 30% canopy cover, pushing stocked forest area upward. However, even while some areas recovered back into stocked status, other forest areas continued to be hollowed out by illegal logging and energy demand from rural populations. Average stocking rate of the country's forests – the number of trees per hectare of forest area – declined over the period[11] and total growing stock and forest biomass was relatively stable.[12] The energy poverty, flooding, erosion, and landslides resulting from severely degraded forests quickly drew the attention of policymakers after the government stabilized in the mid-1960s.

South Korea's forestation policies began to take off in 1967, when the government's forest agency was promoted from a bureau under the Ministry of Agriculture and Forestry to an independent Forest Service reporting directly to the President.[13] South Korea's first national park (Mt. Jiri) was established in 1967, and the Forest Service began to enforce a law against slash-and-burn farming that was passed the previous year. This was also the first year of the country's second five-year economic development plan, which elevated forest reclamation and the establishment of specific fuel-wood forests as tools to control erosion and provide food security. President Park Chung Hee took a personal interest in forest recovery, participating directly in tree planting and communicating his support clearly to both policy makers and the general public – along with government messages about forests that appeared on cigarette packs, stamps, and in radio broadcasts. The five-year plan had an annual target of 150,000 hectares of forest restoration per year, with central government-funded tree nurseries in most villages, collectively seeking to raise 1.4 billion tree seedlings per year. Village forest cooperatives helped determine the locations and species for reforestation of fuel-wood forests. They also mobilized compulsory labor for planting and

[6] Bae et al 2012.
[7] Republic of Korea report to FRA2010.
[8] Bae et al 2012.
[9] NC3. Two species comprise about two-thirds of South Korea's forest stock – Korean pine and Oriental chestnut oak. For comparison, timber volume of 10 $m^3$/ha of Korean pine would be equivalent to about 4 tC/ha (14 $tCO_2$/ha) of living biomass (above and belowground) while 10 $m^3$/ha of Oriental chestnut oak would be equivalent to about 7 tC/ha (26 $tCO_2$/ha), both using conversion factors from Choi et al (2002). For comparison, temperate mixed woods have a global medium carbon density of about 70 tC/ha and a maximum of about 140 tC/ha (ORNL).
[10] Bae et al 2012.
[11] Bae et al 2012.
[12] Choi et al 2002.
[13] The historical account in this paragraph and the next are taken largely from Lee 2013; many elements are confirmed in Bae et al 2012, Choi et al 2002, and in South Korea's National Communications to the UNFCCC.

post-planting management, with rights to gather fuelwood in village commons granted only to households that provided labor for tree-planting during March and April of each year. Wages were provided in food or cash for tree planting outside village forests, for example in erosion-control projects. During this period, the Forest Service not only supported fuel-wood forests, but also multi-use forests and timber plantations, along with urban tree-planting. Surveys in 1972 found 435,000 hectares of surviving reforestation projects out of 784,000 hectares of total replanting (i.e. a 55% survival rate).

Large-scale reforestation action was politically elevated in the 1970s, after a flood that killed 300 people downstream of a severely degraded forest area sparked renewed urgency by the federal government. The Forest Service was transferred in 1973 to the Ministry of Home Affairs in a reorganization that elevated both national and local forestry officials into strategic positions with closer ties to the police force and to economic development officials. A full-scale "10-year forest rehabilitation plan" was launched that was closely entwined with the development goals of a concurrent 10-year economic planning period from 1973-1982. The government set a goal of completing forest rehabilitation of the entire country during the 10-year period by planting 2.1 billion trees on 1 million unstocked hectares of South Korea's 6.65 million hectares of designated forest area. The earlier model of devolving responsibility for reforestation to local officials continued with greater resources and direct authority, including for enforcement of restricted areas, along with performance-based budget allocations that based village funding for tree planting on prior-period success, and direct accountability for failures. A one-month national tree planting period was established each year, and local nurseries operated year-round to produce seedlings of commercial timber species, other fast-growing species, and chestnuts as a food source. Tree-planting and post-planting management was the responsibility of local government, while police provided enforcement against illegal cutting and forestry officials provided technical guidance. The effort was framed not as a program, but as a movement, with the head of the forest service declaring that "first we should plant trees in the hearts of the people." It was also tied into existing community civic organizations (the "*Sae-Ma-Ul*" movement") that emphasized diligence, self-reliance, and cooperation in each village. Survival rates of planted forests may have increased during this period[14] with a greater emphasis on "forest tending" including pest control and fire management. The government declared success on the 10-year forest rehabilitation plan in 1979 (four years early) with 2.8 billion trees planted on 1.08 million ha of land in six years.

Forestation continued to be a focus when a second 10-year forest rehabilitation plan was launched for 1979-1989. This period saw more emphasis on commercial-scale production forests and a more diverse species mix (although still with more non-native than native species), as well as a more centralized forest land-use planning effort, with a national classification survey dividing forests into reserve and non-reserve areas. Political responsibility shifted back to the Ministry of Agriculture and Forestry during this second period, and tree planting decreased in importance as a major theme of the national government even while successful reforestation efforts continued. In total, South Korea planted 4.88 billion trees on 2.05 million hectares from 1973 to 1987 over the course of its two 10-year forest rehabilitation planning periods. The national government invested a total of 592 billion Korean won (~USD 1 billion nominal, or 3 billion in 2016 USD) during this 16-year span, more than 1% of the total national budget.[15]

[14] Lee 2013 claims a 90% success rate during this period without further citation.

[15] Youn et al 2006. Nominal USD calculation applies an annual average USD-KRW exchange rate for each year from 1973-1987 to an assumed average annual expenditure of 39.5 billion KRW; 2016 real USD estimated from nominal USD using GDP deflators.

## Forest Definitions and A/R/R in the South Korean Context

South Korea, in its reports to the FAO Forest Resources Assessments, provides a national definition of "forest" as follows: "It consists of stocked forest land and un-stocked forest land. Stocked forest is land spanning more than 1 hectare with trees and a canopy cover of more than 30 percent. The number of young tree[s] per ha is more than 1,200 in coniferous forest and 1,600 in broad-leaved forest, respectively. Un-stocked forest is land spanning more than 1 hectares with trees and a canopy cover of less than 30 percent, and includes non-stocked land, denuded land, reclaimed land, and miscellaneous forest land. The non-stocked forest lands are forested lands. The miscellaneous forest lands include rock, roads, grave/cemetery, nursery, orchard, military facilities etc." (RoK report to FRA2010 and RoK report to FRA2015). Non-stocked forests are forest with canopy cover between 10% and 30%. No further definition of "denuded land" or "reclaimed land" is provided. There are no reported areas of "other wooded land" or "other land with tree cover." The only adjustment between South Korea's national definition and the area reported as forest to the FAO is the exclusion of "miscellaneous" forest lands.

Korea states in its reports to the FAO that is uses the standard FAO definitions of afforestation and reforestation. Reforestation areas are reported to the FAO for all years in both reports, but afforestation area and natural forest expansion (along with their sum, forest expansion) are reported as "N/A." Korea notes that "afforestation is very rare and [there is] no data," and also that there is no data for natural forest expansion.

Two of the three key terms – afforestation and reforestation – are common in Korea's reports to the UNFCCC. In the most recent reports (TNC and BUR), usage appears to make a distinction between the two based on previous land use: "afforestation" is used primarily in reference to policies and measures to promote planting of forests in urban areas and on private lands that are unused, vacant, or idle, while "reforestation" is used to describe South Korea's historical planting efforts and with respect to replacing damaged or unhealthy forests with new forests of a different species mix.[16] The term "forest rehabilitation" is also used to describe the historical forest turnaround. "Maintenance and enhancement of carbon sequestration potential" is also included as a forestry-related mitigation measure. In earlier reports, usage was less precise, with the same actions and history referenced alternatively as afforestation and reforestation. "Restoration" is used by RoK in reference to watersheds, ecosystems and species broadly, and is specific to *forest* restoration only in the context of international cooperation and additional research needs, but not forest or mitigation history or future policies and measures.

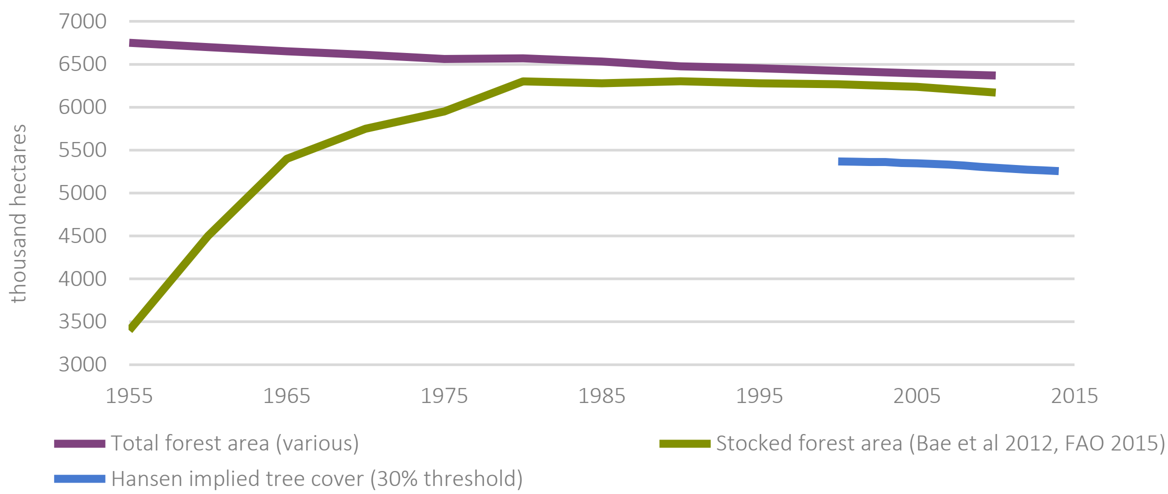
We use the term "reforestation and restoration" (R/R) below to describe Korea's forest actions, consistent with the terms as defined for this paper. This combined term includes the planting and seeding of areas designated as forest (regardless of previous cover threshold). It is also consistent with Korea's use of the term "forest rehabilitation" in its TNC and in its forestry planning documents.

[16] In the TNC, Korea reported "annual afforestation of 2,000 ha" since 2008 – compared to over 20,000 ha per year of "reforestation" over the same period reported to FRA2015.

## Forest Area and Carbon Mitigation Impacts

The results of South Korea's reforestation and restoration efforts are clearly reflected in forestry statistics such as stocked area and stocking rates, and emissions data, with strong agreement from government and literature sources. Total forest area (using Korea's national definition of forest, based on land use and land registration and including both stocked and unstocked forest) has slowly declined from nearly seven million hectares (72% of land area) in the late 1920s[17] to 6.37 million hectares (64%) in 2010,[18] a total decline of 8 to 9% in absolute forest area with an average annual rate of loss of about 0.10 to 0.12% $y^{-1}$. Stocked forest area statistics, on the other hand, reveal a dramatically different story. Total stocked forest area increased from a mid-1950s low of 3.4 Mha (50% of total forest area)[19] to 2010 levels of 6.17 Mha (96.9% of total forest area, and over 99% of total forest area excluding miscellaneous forest)[20] (Figure 1). Hansen et al (2013) provides one independent – albeit imperfect – check on South Korea's National Forestry Inventory data for the years 2000-2015. Tree cover in the year 2000 at 30% threshold is 14% lower in Hansen et al (2013) than the stocked forest area reported by South Korea, but this difference could be explained by the difference in minimum forest area definition – 0.09 hectares in Hansen versus 1 hectare for RoK. The general forest cover gains and losses in Hansen et al (2013)—an average of 10,000 hectares gross loss per year from 2000-2015 and only 2,000 hectares of average gain per year from 2000-2012—are consistent with the average stocked forest area loss of about 8,500 hectares per year reported by South Korea to FRA2015.

**Figure 1. South Korea's Forest Area**




Note: Total forest area is compiled from Korea's TNC (2012), BUR (2014), and report to FAO (2015), with additional data prior to 1970 and for 1975 and 1985 from Bae et al (2012), which compiled estimates from official government statistics and estimated missing years. Stocked forest area is compiled from FAO (2015) for 1990 and 2000-2010, and from Bae et al (2012) for other years, also compiled from government sources or estimated. Hansen implied forest area is calculated as 2000 tree cover minus annual tree cover loss, both at 30% cover threshold, plus average annual tree cover gain at 50% cover threshold. Stocked forest is defined as land spanning more than 1 hectare with trees and a canopy cover of more than 30%, while total forest includes unstocked forest area with canopy cover below 30%.

It is difficult to directly compare total forest area or stocked forest area over time to the replanted and rehabilitated area totals for several reasons: some replanting likely takes place in understocked forests

[17] Bae et al 2012.

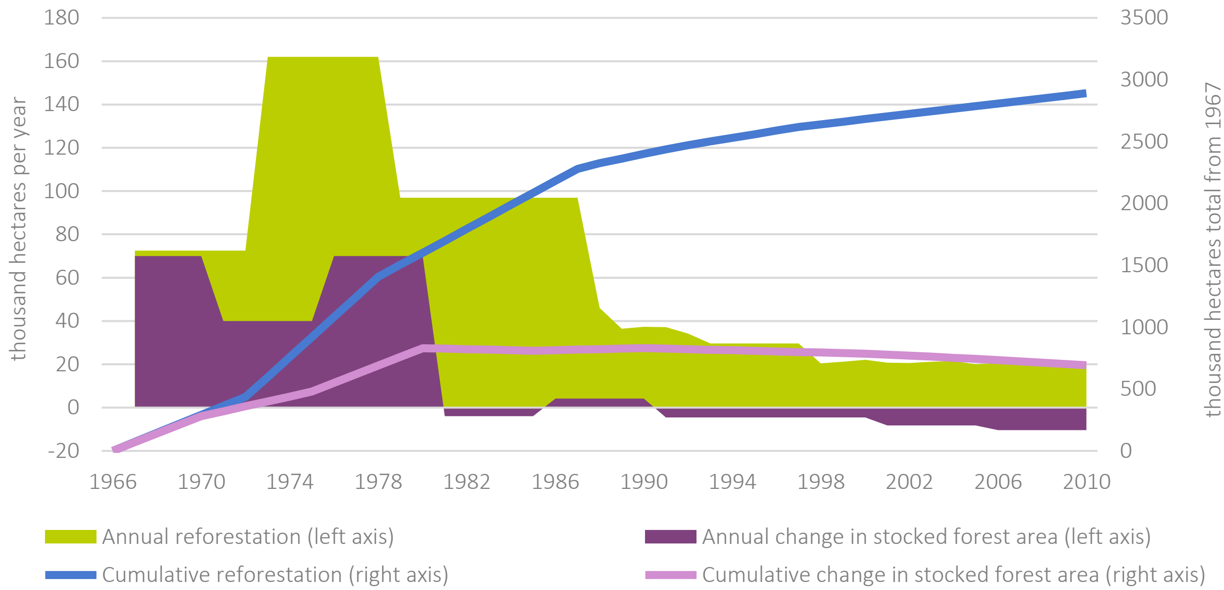
[18] FRA 2015. Korea reports values of 6.172 Mha stocked forest (defined as land spanning more than 1 hectare with trees and a canopy cover of more than 30%), and 6.37 Mha of total forest including all forest types. Total land area in 2010 is 9.99 Mha.

[19] Bae et al 2012.

[20] RoK report to FRA2015.

that nonetheless exceed the 30% threshold; and it is not possible to know how much replanting is likely used to maintain stocked forest at a constant level in response to fire and pest outbreaks or from timber harvests – while fire and pest outbreak area is reported, it isn't clear if such areas are degraded sufficiently to require replanting, and timber harvest volume is provided but not harvested area. Cumulative R/R area from 1967 to 1980 was about 1.6 Mha, while stocked forest area only increased by 0.6 Mha over this period from about 5.7 to 6.3 Mha. From 1980 to 2005, another 1.2 Mha of R/R took place, while stocked forest area actually declined slightly over this period (Figure 2).

Figure 2. South Korea's Reforestation and Restoration vs Stocked Forest Area Change 1965-2010




Note: Reforestation and restoration area from 1967 to 1987 is based on period average estimates calculated from period totals in Lee 2013 for the second 5-year economic development period and the two 10-year forest rehabilitation planning periods respectively, assuming a 90% success rate for the latter two periods as cited by Lee (2013). Reforestation and restoration estimates from 1988-2010 are from "reforestation" values reported to FAO 2015, with missing data from 1993-1997 interpolated from the 5-year periods immediately preceding and following. Stocked forest area is based on Bae et al (2012) from 1967-1990, and on FAO (2015) for 1991-2010.

The recovery of South Korea's forests is more evident in terms of stock data such as wood volume and carbon stock. Bae et al (2012) reconstructed the history of South Korea's growing stock from official forestry data, estimating that the average growing stock volumes increased from about 10 $m^3\ ha^{-1}$ in the mid-1960s to just over 20 $m^3\ ha^{-1}$ in 1980 and then accelerating to reach nearly 100 $m^3\ ha^{-1}$ in 2007. The age distribution of South Korea's forest stock—59% of its trees in 2010 were less than 30-years old—is a result of its intensive reforestation and restoration programs from the 1960s through the late 1980s. In 2010, its relatively young forest were increasing growing stock by 3-4% $y^{-1}$ and exceeded 125 $m^3\ ha^{-1}$.[21] South Korea's rapidly increasing average forest growing stock on a relatively stable total forest area has translated into a significant carbon sink over the past 50 years. Total forest carbon biomass rose from about 0.03 GtC in the 1960s and early 1970s to over 0.20 GtC in 2000[22] and likely 0.40 GtC in 2010[23] (Figure 3).

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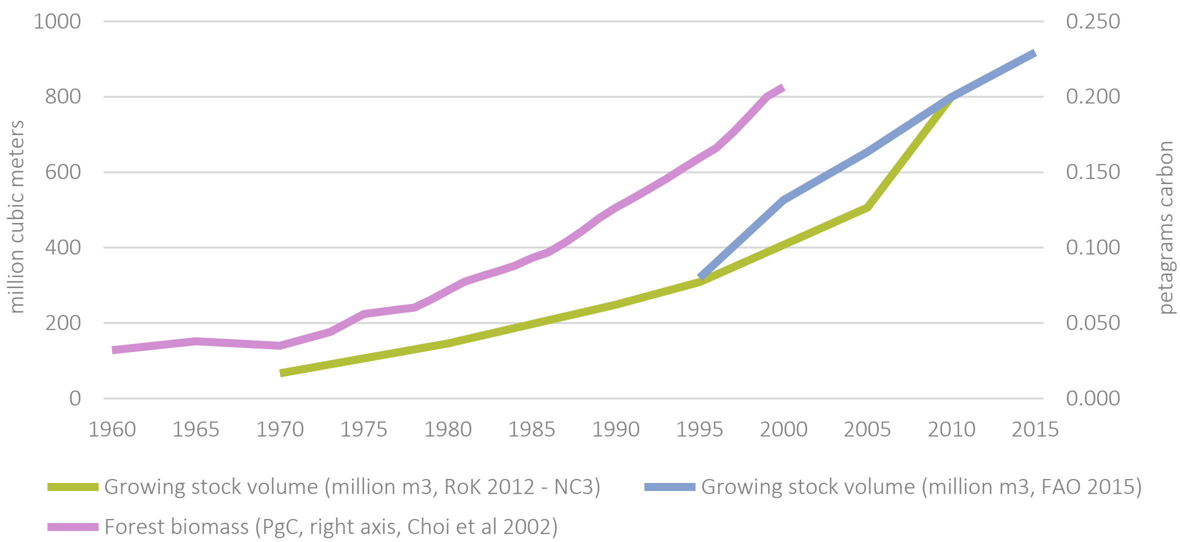
[21] NC3.

[22] Choi et al 2002.

[23] Assumes that the ratio of growing stock volume to biomass carbon remains constant.

Figure 3. South Korea's Forest Stocks



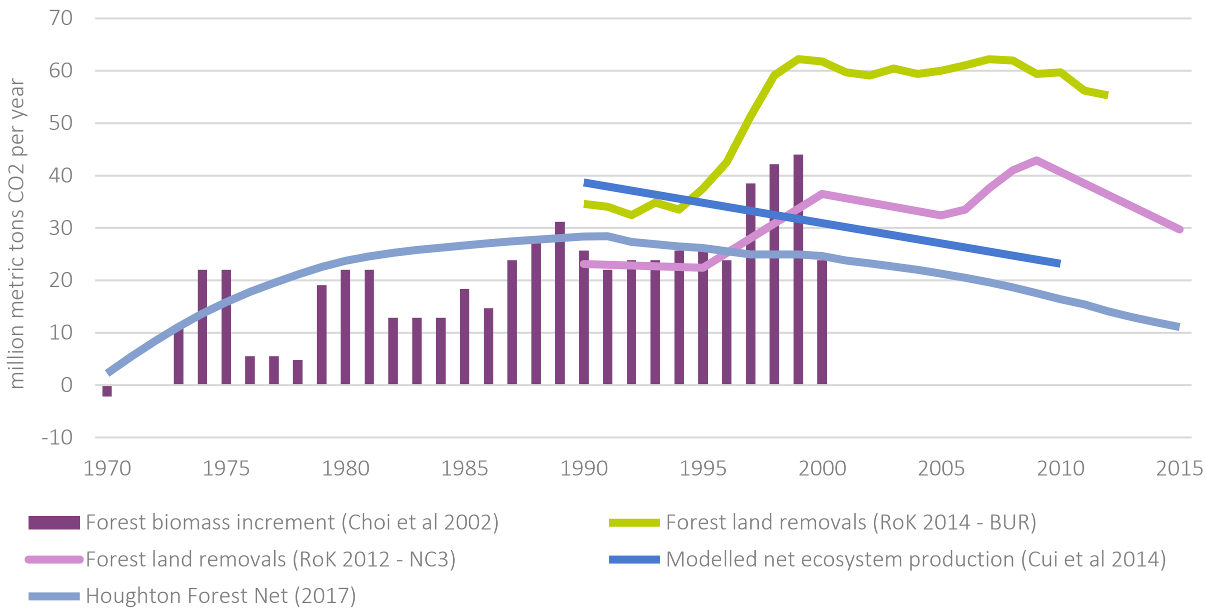

Total forest carbon uptake rates went from near zero in the 1960s to 10 MtC $y^{-1}$ (37 $MtCO_2$ $y^{-1}$) in 2000, although with significant inter-annual variation (Figure 4).[24] The government updated its estimates of the forest sink significantly upward – by nearly a factor of two – between its Third National Communication (NC3) to the UNFCCC in 2012 and its First Biennial Update Report in 2014, explaining to the UNFCCC expert review team in 2016 that these changes were based on improvements in the accuracy of activity data (UNFCCC Secretariat, 2016). However, the expert review also noted that insufficient data were provided to understand these changes, and requested more information in South Korea's next BUR.

Independent research generally supports the scale of South Korea's TNC estimates of its forest sink, although with an increasing divergence in the last decade—four different estimates are plotted in Figure 4 alongside official data. Two independent studies based on South Korea's official forest area statistics show estimates of forest biomass increment (Choi et al 2002) and carbon uptake rate (Lee et al 2002) for the 1990s that are very similar to the National Communications estimates over this period. The size of South Korea's forest sink is expected to decrease in coming years, if it hasn't already. The 2012 TNC suggests that the sink would likely begin to weaken in 2015 and drop to 24 $MtCO_2$ $y^{-1}$ by 2020. The 2014 BUR reported a 10% decline from 2007 through 2012. Two recent independent analyses –a bookkeeping model based on statistics reported to the FAO (Houghton and Nassikas, 2017)[25] and an analysis of net ecosystem productivity based on satellite observations (Cui et al 2014) – suggest that this weakening of South Korea's forest sink may have begun as early as 1990.

[24] Choi et al 2002 and NC3.

[25] Houghton, R.A., and A.A. Nassikas (2017). Global and regional fluxes of carbon from land use and land cover change 1850–2015, Global Biogeochemical Cycles 31:456-472, doi:10.1002/2016GB005546. Country-level data were developed in the article cited (but unpublished). Estimates in this figure exclude transitions between non-forest land uses.

Figure 4. South Korea's Forest $CO_2$ Sinks




There is no doubt that South Korea's policy-led reforestation and restoration efforts had a major impact on its forests. Broader economic forces certainly played a role as well: South Korea's overall economy underwent a major transition during the two forest rehabilitation periods, with economic growth rates taking off in the late 1960s and reaching over 10% per year for much of the 1970s. This economic recovery helped shift the country's primary energy consumption away from wood to coal and oil as the population could afford them. Wood dropped from 90% of South Korea's primary energy in 1950 to about 40% in the mid-1960s and 5% by 1980 (Bae et al 2013). South Korea's rural-to-urban migration took off in the mid-1970's and may also have played a role. In 1970, over 15 million people lived in rural areas (45% of the population), which dropped to 6 million people (15.4%) by 1990 (Bae et al 2013). For these reasons, forest transition in Korea can be attributed to both government action and to economic development.

South Korea's successful reforestation was highlighted by the government in its very first National Communication to the UNFCCC in 1998, in the very first paragraph of its summary. The government has consistently emphasized its implementation of forest policies and measures including both forest protection and reforestation, and more recently forest management, afforestation and (in TNC) wood bioenergy.[26] Forests received less prominent attention in the National Communication narratives over time, as the rapidly industrializing economy increased fossil emissions and as agriculture and forests became a smaller proportion of the country's emissions profile along with their sharply decreasing prominence in the country's economy. Forest sinks have been consistently framed as an offset to the country's growing industrial and energy emissions, both in the National Communications and in independent scholarly work by South Korean scientists (e.g., Choi and Chang 2006). In 2012, the forest sink offset more than 7% of South Korea's emissions, down from nearly 12% in 1990[27] and 31% in 1973.[28]

[26] Terms in this paragraph represent the wording used by South Korea in its reporting, rather than specific definitions.
[27] Estimates from the BUR.
[28] Choi and Chang 2006.

## Summary and Lessons Learned: South Korea Case Study

South Korea experienced one of the most rapid and striking forest transitions in recent history, with forest recovery starting slowly in the late 1950s following the Korean war and accelerating dramatically in the 1970s and 1980s primarily as a result of a government-led reforestation and restoration policy. While forest area declined somewhat as defined by land use, area with forest cover expanded dramatically from 1955 to 1980 as planting increased stocked forest area and tree cover by about 85% (2.9 Mha total, or 116,000 ha $y^{-1}$) from 1955 to 1980, reaching stocking rates of 96-97% of forest land, while forest wood stock volume increased more than 10-fold from 1970 to 2010. The carbon sink from this widespread forestation effort undertaken decades ago has only recently peaked, offsetting as much as 60 $MtCO_2$ $y^{-1}$ of South Korea's industrial emissions from 2005-2010 and declining only somewhat since then.[29]

Several notable factors in South Korea's success:

**High-level leadership was key** to South Korea's successful reforestation and restoration, at both the executive level and at the leadership level within Ministries. For example, President Park was personally invested in the effort, frequently remarking on the effort during speeches. As another example, when the Forest Service was elevated administratively to be housed in Home Affairs, the Minister of Home Affairs (responsible for all domestic economic issues) had daily meetings with the Forest Service during the month of national tree-planting to track progress.

**An effective institutional framework** that promoted inter-ministerial coordination and coordination between different levels of government was a key element in supporting both planting and maintenance of new forest cover in South Korea. For example, national level placement of the Forest Service in Home Affairs allowed close coordination with police and economic functions (e.g., a police superintendent was embedded in the Forest Service to be in charge of forest offenses). Another example was inclusion of regional and local foresters in regional and local economic planning and governing processes, and the learning and knowledge sharing network these foresters achieved.

**Community buy-in and participation was actively cultivated and proved critical** to South Korea's reforestation and restoration programs. To achieve this, communications from the federal government created a sense that forests were critical to South Korea's future and that planting and maintaining trees was patriotic. Communities were rewarded based on performance – for example, an early program document declared "As a village plants more trees, more benefits should go to a village, and this policy should be made known fully in advance." There were also tree-planting contests with funding based on success, and mayors could be (and in a few cases, were) fired if their jurisdictions experienced a forest fire that wasn't quickly controlled.

**Constant and effective monitoring of reforested and restored areas** ensured that progress was real and success rates high. External validation helped: inspectors were rotated to different provinces to avoid false reporting of tree planting scale or success. Direct inspection was supplemented with remote sensing using aerial photographs taken in the mid-1970s to evaluate progress and analyze gaps.

**Enforcement and smart implementation helped prevent cheating.** For example, the national and local police were fully engaged in controlling access to sensitive forests and stopping illegal logging, including close coordination with the Forest Service. And opportunities to "cheat the system" were minimized. For example, to avoid redirection of fertilizer from mass production tree nurseries to farming, slow-release forest fertilizers were manufactured and distributed that were not suitable for agriculture.

[29] See Annex 3 for a summary of South Korea's efforts.

Perhaps most importantly, **forestation efforts were successful to the extent that they were tied in to economic and social circumstances**. Policies were implemented to provide energy needs that were consistent with increasing biomass, such as establishment of fuelwood forests and providing subsidies and equipment for a shift from wood to coal as a fuel source. Alternative lands were made available to slash-and-burn farmers when outlawing the practice in agricultural regulations. Economic development and a mass rural to urban migration helped reduce drivers of deforestation and forest degradation. And while some of the earliest reforestation and restoration efforts preceded such movement of people, the migration and related economic development probably helped "lock in" the sequestered carbon, as there was lower pressure on forests after they recovered.

**The cost of South Korea's reforestation and restoration** during the peak years of effort from 1973-1987 was nearly USD 200 million $y^{-1}$ totaling USD 3 billion over 15 years. That is equivalent to about USD 1,440 to USD 1,600 per ha planted, or about USD 12.9 per $tCO_2$ sequestered over the same period.[30]

Several lessons also emerge from the South Korea case study in terms of the data, information, and analyses needed to understand the impacts of A/R/R efforts:

**Forest area and carbon content need to be examined together** to understand the complex dynamics of forest loss and recovery, and their relationships to policy. An approach that looks solely to forest area as an indicator might yield false conclusions. In South Korea's case, forest data show a long, slow decline by a land-use forest area definition; a stark drop and fast recovery in the 50s by a canopy cover definition ("stocked forest"). The longer-term impact of forest recovery through the 1970s-1990s is only revealed when forest carbon stock statistics – which respond on decadal scales – are examined.

**A/R/R objectives advanced in the climate context should be outcome-based (e.g. tons of carbon, cubic meters of wood stock) rather than input-based (e.g. hectares or trees planted).** South Korea's program targets were terms of "hectares of forest rehabilitated" and number of seedlings planted. However, the impact may be vastly different depending on the type of reforestation or restoration pursued, what type of seedlings are planted, where the action takes place, and how successful it is. Planting 2000 seedlings in one hectare of fully denuded recently burned forest "achieves" only one hectare of reforestation; planting the same 2000 seedlings to fill gaps in growing forest that is already at 60% tree cover might "achieve" 20 hectares of restoration. Conversely, 2000 seedlings planted to provide windbreaks or prevent erosion might allow natural recovery of adjacent lands and achieve far more carbon impact than 2000 seedlings planted in a single hectare. In this sense, A/R/R inputs are only tenuously related to expected forest outcomes, making input-based goals hard to interpret at best, and meaningless at worst. In South Korea's case, nearly three million hectares of reforestation and restoration action from 1966 to 2010 was unrelated to changes in forest area (as the country defines it), and resulted in stocked forest area increasing only through 1980. Without complex modeling and additional data and/or assumptions, it is nearly impossible to relate outcomes—such as carbon uptake and increases in forest biomass and growing stock volume—to input-based restoration and planting goals.

**The carbon impact of large-scale A/R/R efforts – and thus the cost of emission reductions – is difficult to attribute without an explicit business-as-usual scenario**. It is quite clear that South Korea undertook large-scale reforestation and restoration efforts from the late 1960s to the late 1980s, and that forest stock volumes, biomass, and sequestrations all increased dramatically in the following decades. However, some theorists suggest that forest pressures diminish and ultimately reverse as a country's wealth increases,[31] as South Korea's did, making attribution difficult.

[30] Values in real 2016 USD. Range is per ha planted (low) or per ha successful (high) as estimated by Lee (2013). Estimate of sequestration cost is based on changes in forest biomass from Choi et al (2002), and does not account for time delays in sequestration from R/R.
[31] There is still significant debate about this "environmental Kuznets curve" theory as applied to forests.

## China: An Unparalleled Scale of Tree Planting

China's forest area declined steadily by about 2.7 million hectares per decade over the 18th and 19th centuries as population grew and forests were degraded into open "woodland" or converted to cropland and urban areas, shrinking a total of 30%-40% over the period.[32] The loss accelerated in the first half of the 20th century to upwards of seven million ha per decade, with most historical reconstructions suggesting a forest area nadir sometime between 1950 and 1980 at total forest extent in the range of 80-107 Mha (8.6% - 11.1% of China's land area).[33] These decades were a transition stage for China's forests, with overall forest cover unstable. Timber production was the primary goal of forest management over this period, with steadily increasing harvests primarily in natural forests. Plantations began to be established over this period, with the earliest large-scale plantations reaching harvest age and substituting for natural forest harvests by the late 1970s.[34] By the end of this period, annual harvested volumes exceeded annual growth, and China's forest age structure shifted towards younger forests.

This approach to forests as a timber resource above all else began to change in the late 1970s. Desertification and the southern advance of the Gobi desert toward China's major agricultural areas began to be perceived as a major threat to China's food security, while degradation of the region's soils and vegetation were already decreasing and destabilizing food production and choking downstream waterways. In 1978, the government launched the largest forestation project ever envisioned – a "forest shelterbelt program" to establish a Great Green Wall against the advance of the Gobi. The still-ongoing Three-North(s) Shelter Forest Program (TNSFP) set out to plant 100 billion trees in three periods over 73 years to establish 35.1 million ha of protective forest across 2,800 miles of northern China, increasing forest cover in the region accounting for 42% of China's land area[35] from 5% to 15%.[36] The Agriculture and Forestry Ministry was split when the TNSFP was launched, with a State Forestry Ministry established to manage the massive afforestation program. Tree planting included firewood forests to substitute for broader fuelwood gathering; shrub forests to provide fodder for livestock farming; "economic forests" for production of nuts and fruit; and plantation forests to provide timber and pulp. Alongside the launch of the TNSFP, the government launched a Wildlife Conservation and Nature Reserves Program to protect existing forests and natural areas from further degradation as demand for forest products was intended to shift to newly afforested areas.

While these programs demonstrated the government's increasing consideration of the ecological significance of forests and the provisioning of non-timber forest products for local communities, large-scale timber production remained a primary goal of forest management throughout the 1980s. Timber extraction from China's forests continued at relatively high volumes, albeit shifted largely to plantations rather than the natural forest harvests of past decades. Shelterbelt afforestation began to increase total forest area in China from the early 1980s to the early 1990s[37] and natural forests began to recover from previous overharvesting. By the end of the first period of the TNSFP in 2000, the government had

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[32] Liu and Tian 2010.

[33] Ibid, Table 6, which compares the authors' historical forest area estimates to 12 other sources. Both Liu and Tian and an independent reconstruction by Zhang and Song (2006) place the nadir in 1950 at a bit over 80 Mha, with increases thereafter. China's first national forest resource survey estimated forest cover of 11.8% in 1962, along with a net loss from 1950-1962 of more than 6 Mha estimated from harvest, planting, and regeneration data. These estimates are inconsistent with the 1949 Ministry of Forestry estimate of 8.6% forest cover, suggesting it was a significant underestimate. Houghton and Hackler's (2003) reconstruction suggests that forest area was 23% lower in 1980 than 1950, but does not identify the timing or level of a minimum.

[34] Zhang and Song, 2006.

[35] Duan et al, 2011. The program covers most of 13 northern provinces, which together represent 30% of China's tree canopy cover at a 20% cover threshold in the year 2000, according to WRI's Global Forest Watch.

[36] SFA 2016.

[37] Zhang and Song, 2006.

invested RMB 7.3 billion (excluding labor, likely in the range of USD 1.2-4.7 billion)[38] and completed 22 Mha of "afforestation," including 15.4 Mha of "artificial plantings."[39]

During the 1990s, two related environmental crises precipitated a reassessment of forest and land policy in China. Dust storms born of soil erosion on the Loess Plateau in north central China that had periodically darkened the skies of China during the 1980s became unbearable during the "Black Wind" of May 1993, a storm that killed hundreds of people and destroyed hundreds of thousands of hectares of crops before choking Beijing's seven million people. A few years later during the summer of 1998, devastating floods swept through the middle reaches of the Yangtze River and other northern Chinese watersheds after torrential rains, killing thousands and leaving 15 million people homeless after a 100,000 square kilometer evacuation. Like the duststorms before them, these floods were also attributed to massive land degradation and soil erosion, which together delivered two billion tons of silt into the "Yellow River" annually and diminished the water-holding capacity of hillsides and other "sloping land."[40]

China responded with the launch of its "Six Key Forestry Programs" in 1998, which added new large-scale tree planting programs to the 20-year old forest shelterbelt program[41] (Table 1). From 2000 to 2009, China invested RMB 725 billion (USD 113 billion) in these programs with a combined afforestation target of about 55.6 Mha over the period (Table 1)[42] and a coverage of nearly 97% of China's counties. Independent analysis available at the time suggested that about 130 Mha of land was available for "afforestation"[43] (Xu 1995). In other words, China intended to afforest nearly half of its available land in just one decade. The Grain for Green Project (GGP), the largest program, directly subsidized some afforestation but primarily took a payments-for-ecosystem services approach, compensating landholders with grain and/or cash subsidies for reestablishing grasslands and forests on degraded or steeply sloped farmland or on barren lands, with payments up to eight years after conversion.[44] GGP has formed the core of China's Loess Plateau restoration efforts since 2000 (Xiao 2014), although the TNSFP and other forestry and desertification reduction programs in the region also contributed.

The six programs have together contributed to a remarkable reversal of decades of forest loss and degradation in many regions. Impacts of the programs on the Loess Plateau have been particularly well studied. The Loess Plateau shifted from a net carbon source in 2000 to a net sink in 2008, resulting in a total of 96.1 MtC sequestered in live biomass and soils over the period. Areas of increased carbon removals were highly spatially correlated with restored areas (under the GGP program). This increased sequestration can be attributed to average tree cover increasing by 1.89 Mha (41%) from 4.62 Mha (7.44% of the Plateau area) in 2000 to 6.51 Mha (10.49%) in 2010.[45]

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[38] SFA 2016. States that "up to the year of 2000, the first period completed an accumulative investment (excluding labor inputs) of RMB 7,266.9 million." It is not clear if the amount cited is real or nominal RMB, nor is it broken down by year. Over the period 1978-2000, the USD:RMB exchange rate ranged from 1.7-8.6, making conversion difficult. If the figure represents real RMB at the time of the study, it would be equivalent to 2016 USD 1.2 billion. If it represents total nominal RMB over the period, assuming a constant spend rate over the period would be 2016 USD 4.7 billion total. The USD conversion would be higher if the RMB spend rate started high and declined, and less if it increased over the period.

[39] SFA 2016. See below for definitions. China includes natural regeneration facilitated by enclosures as "afforestation," contrasted with "artificial plantings." The source does not specify if these amounts represent total afforestation, or only successful afforestation.

[40] Z. Xu et al 2004.

[41] By this time, the shelterbelt program had expanded from the Three-North area to also include shelter forest planting in the Yangtze River valley, the Pearl River valley, and other regions.

[42] Cao et al 2011 (a). Estimate assumes that two-thirds of 2001-2015 target would be the 2001-2010 target. Currency conversion to nominal USD based on annual average exchange rates and expenditures; in 2016 real dollars, expenditures were about USD 113 billion.

[43] This estimate included 105 Mha of shrubland, wildland, and recently cut and burned areas that could be planted, and 25 Mha of open forests and sandy wastelands that could be actively managed for greater tree cover, and excluded over 70 Mha of dry cropland that was potentially appropriate for agroforestry rather than afforestation.

[44] Ecologically restored areas were expected to provide some economic returns to landholders after compensation ceased, either from grazing of grasslands, fruit and other non-wood forest products from economic forests, and wood from arbor forests.

[45] Xiao 2014.

Table 1. China's "Six Key Forestry Programs"[46]

| Project | Goals | Target planted area | Time period |
|---|---|---|---|
| Three Norths Shelter Forest System Project (TNSFP)[a] | Desertification control | 9.5 Mha<br>15.4-2247 Mha<br>35 Mha | 2001-2010 (Phase IV)<br>1978-2000 (1st period)<br>1978-2050 (total goal) |
| Wildlife Conservation and Nature Reserves Program | Conservation | - | 1978-? |
| Sand Control Program[b] | Desertification/dust storm control | 5.2 Mha | 2001-2010 |
| Grain for Green Project (GGP)[c] | Soil and water conservation | 3248 Mha | 2001-2010 |
| Natural Forest Conservation Program[d] | Soil and water conservation | 4.4 Mha | 2000-2010 |
| Forest Industrial Base Development Program[e] | Wood production | 13.3 Mha | 2001-2015 |

Notes: a. The largest Shelter Forest Project; expanded to include the upper and middle Yangtze, Taihang Mountains, Coastal areas; afforestation area targets were not identifiable for the smaller shelterbelt programs. b. Also known as (*aka)* the Green Shield around Beijing and Tianjin or the Beijing-Tianjin Sand Source Region program; it also supports non-forest re-greening. c. *Aka* Conversion of Farmland to Forest Program, or Sloping Land Conservation Program. d. *Aka* Natural Forest Protection Program. e. *Aka* Development Program for Fast-Growing and High-Yielding Forests.

However, differences between outcome-based monitoring and government figures suggest that efforts may have been less effective than expected. For example, tree cover increases on the Loess Plateau as estimated from MODIS data (1.89 Mha from 2000 to 2010) were only half as large as estimates of afforested area by the Ministry of Forestry in the three provinces comprising the majority of forests on the same area (3.8 Mha from 1999 to 2012).[49] The difference between government afforestation statistics and observed tree cover increases suggests some combination of establishment failure, immature planted areas that were not detectable or not tall enough to be classified by remote sensing, and/or afforestation in already-forested areas. The first explanation is likely, at least in part: mortality has been high in many of China's afforestation projects, suggesting a gap between the ambitious scale of action and actual recovery of forests. Survival rates of trees in China's afforestation projects from 1952-2005 has been 24%, with survival rates over the same period in the drier regions of the TNSFP only 15%.[50]

While there is strong evidence that tree planting programs had positive impacts from a carbon and productivity perspective, unintended negative consequences have also been observed. A study of ecosystem service changes on the Loess Plateau from 2000-2008 finds that conversions of farmland to woodland and grassland enhanced soil conservation and carbon sequestration, but decreased water provisioning during a warming and drying climatic trend. These changes were attributed to strong socioeconomic incentives of the GGP and other restoration policies.[51] Other field studies of GGP areas on the Loess Plateau showed evidence that afforestation in the more arid regions of the project could increase the severity of water shortages, decrease streamflows, reduce species diversity, and decrease vegetation cover in some afforested plots (even as the average cover across all areas increased).[52] These results suggest that exclusion of grazing and farming to allow return of native vegetation may be more appropriate tools for ecological restoration of arid and semi-arid areas than afforestation, which (where appropriate) should use native species such as high water-use efficiency dwarf shrubs.[53]

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[46] Table after Cao et al 2011 (a). Additional information in the table from "Implementation of Six Key Programs."
[47] SFA 2016 describes 22 Mha of afforestation, including 15.4 Mha of "artificial plantings," suggesting that the former includes some natural regeneration and/or seeding from planes.
[48] Cao et al 2011 and Chen et al 2009, which further cites achievement of 24.24 Mha by the end of 2007.
[49] Xiao 2014.
[50] Cao et al 2011a.
[51] Lu et al 2012.
[52] Cao et al. 2009 JAE; Hua et al 2016; Cao et al 2011b; Wang and Cao 2011b.
[53] Cao et al. 2009 JAE

## Forest Definitions and A/R/R in the Chinese Context

China's National Forest Inventory uses multiple categories of forest rather than a single forest definition. In its country report to the FAO Forest Resources Assessments (2014), China describes its national forest classification categories, including: a) arbor forest, including natural forests and timber plantations; b) economic forest, whose main purpose is for non-wood forest products and fruit; and c) bamboo forest. Arbor and economic forest are defined in part by having a canopy cover of more than 20%. China groups these three categories together as "forested land" in what may be considered China's national forest definition.

China defines "afforestation" in its national classification system as "the area including the barren hills, wasteland, sand dune and cropland converted to forest land planted by manual seeding, air-seeding, planting and planting with cuttings, and qualified acceptance with inspection." China also tracks and reports on a number of additional land use categories related to afforestation, such as areas where afforestation activities are occurring, but do not yet meet afforestation thresholds (separated into those expected to do so within 3-5 years and those that are not), and "other non-stocked forestry land" which includes areas prepared for afforestation but not yet planted. Also, relevant to afforestation is the area of "forest suitable land," defined as areas planned for planting. Taken together, these classifications and definitions suggest that "afforestation" is defined by China based on canopy cover transitions rather than a change in land use.

The term "reforestation" is not used by China's national forest inventory, although "slash regeneration," defined as "forest formed in cut-over and fired areas by planting/seeding or man-improved natural regeneration" would be reforestation.[54]

"Restoration" is also not a key term in China's NFI, although "afforestation under tree canopy through complementary planting" is reported to FAO for years 2007-2012 as distinct from other reported afforestation area, which falls squarely within the definition of restoration in this paper. The areas reported in this category are quite small compared to other actions, and aren't included below.[55]

China also tracks and reports on its extensive efforts to enclose hillsides "for afforestation," which fall into a definitional grey area. This paper treats these areas as "human-assisted natural regeneration," and generally excludes them from the scope of A/R/R. However, if new forests established as a result of enclosures are considered "human-induced" rather than natural regeneration, they would be considered reforestation or restoration. While significant areas are reported in these categories, they are not included as afforestation unless otherwise noted.

"Afforestation" is the dominant A/R/R related term used in China's reports to the UNFCCC. It is used to reference historical actions and plans for future mitigation from increasing carbon sinks. The term "afforestation" below is used to represent China's formal definition, noting that it is consistent with this paper's definition as well. However, China also uses the term in a more general sense – for example to describe planting under tree canopies, which is "restoration" in this paper; and to describe the goal of hillside enclosures, which is treated below as natural regeneration. When used in this broader sense below (for example citing China's own usage), it will be put in quotation marks. "Afforestation and reforestation" is used when including slash regeneration.

[54] The area of slash regeneration from the NFI data is assigned to the FAO category of reforestation after downward adjustments by 7-15% to include only arbor forests and exclude economic and bamboo regeneration.

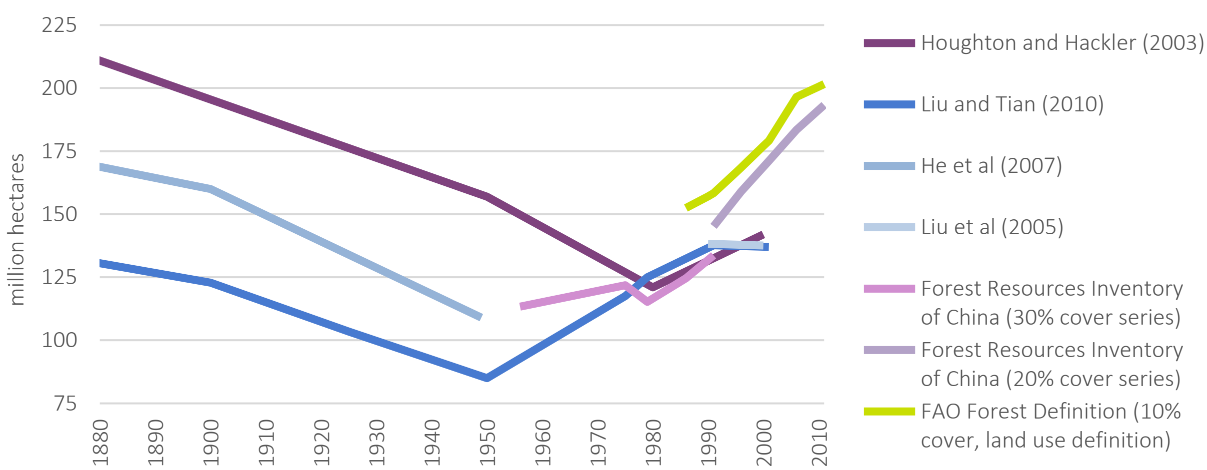
[55] An average of 116,000 ha $y^{-1}$ of "afforstation under tree canopy" is reported for 2007-2012, compared to reported afforestation area in the range of 5 Mha $y^{-1}$ and annual "slash regeneration" ranging from 286,000 ha to 1 billion ha. It is not clear whether this area is also included in other reported afforestation data.

## Forest Area History and Impacts

Long-term reconstructions of China's forest area consistently show a steady decline over the 18th and 19th centuries, with further and more rapid declines in the first half of the 20th century (Figure 5). Most assessments of more recent forest area history rely upon official government statistics, primarily from a natural resources survey completed from 1950-1962 and a series of Forest Resources Inventories each covering five year periods with the first completed in 1976. These inventories also form the basis of China's reports to the FAO, with area statistics adjusted to reflect FAO definitions of forest rather than domestic definitions of forest.[56] A potential error in the 1949 natural resources survey and a lack of data from 1963-1972 makes it difficult to tell if forest area reached a nadir around 1950 and increased steadily through the mid-1970s, or whether it was more stable in these decades.[57] Regardless, all series show increases in forest area subsequent to the 1977-1981 inventory, during which the Three Norths Shelter Forest Program was established. Zhang and Song describe three distinct periods of Chinese forests as defined by cover: a transition stage from 1949-1981 with unstable forest cover; a decade of slow increase from 1982-1993; and a period of rapid increase starting in 1994.

How much has forest area increased in recent decades? Most of the available estimates are based on the Forest Resources Inventories of China (FRIC). At the lower end, Liu and Tian (2010) estimate a forest area increase of 19.5 Mha from 1975-2000 (750,000 ha $y^{-1}$). More recent estimates suggest a much larger gain. Using China's forest definitions and FRIC data,[58] forest area increased from about 115 Mha in 1979 to 193 Mha in 2011, although this includes a shift in forest definition from a 30% cover threshold to a 20% cover threshold that accounts for about 11.5 Mha of the increase. After adjusting for the definition change, this is an increase in forest area of 66.5 Mha (2.08 Mha $y^{-1}$). Using an FAO forest land-use definition of forest area and 10% cover threshold rather than China's domestic 20% forest cover definition yields a similar result – about 49 Mha increase from 1986 to 2011 (1.97 Mha $y^{-1}$).[59]

**Figure 5. China's forest area**




[56] China's national inventory uses a land cover definition of forest with a 30% cover threshold through the Fourth Inventory (1989-1993) and a 20% cover threshold after that, and include bamboo forests and fruit orchards. China adjusts its FAO forest area statistics to match a land use definition and a 10% cover threshold by including open forest land (between 10% and 20% cover) and un-stocked forest land of various types.

[57] Most official statistics indicate a 1949 forest cover of 8.6% of country area, which is inconsistent with the forest area changes and total forest cover estimates from the 1950-1962 survey, which found a 1962 forest cover of 11.81% of country area, a net decrease in natural forests over the period by 1.2% of country area, and net increase in plantation forests by 0.53%, suggesting an overall net forest area loss of 0.67% of land area. Based on these survey estimates, 1949 forest cover would have been close to 12.5% of land area. Zhang and Song 2006.

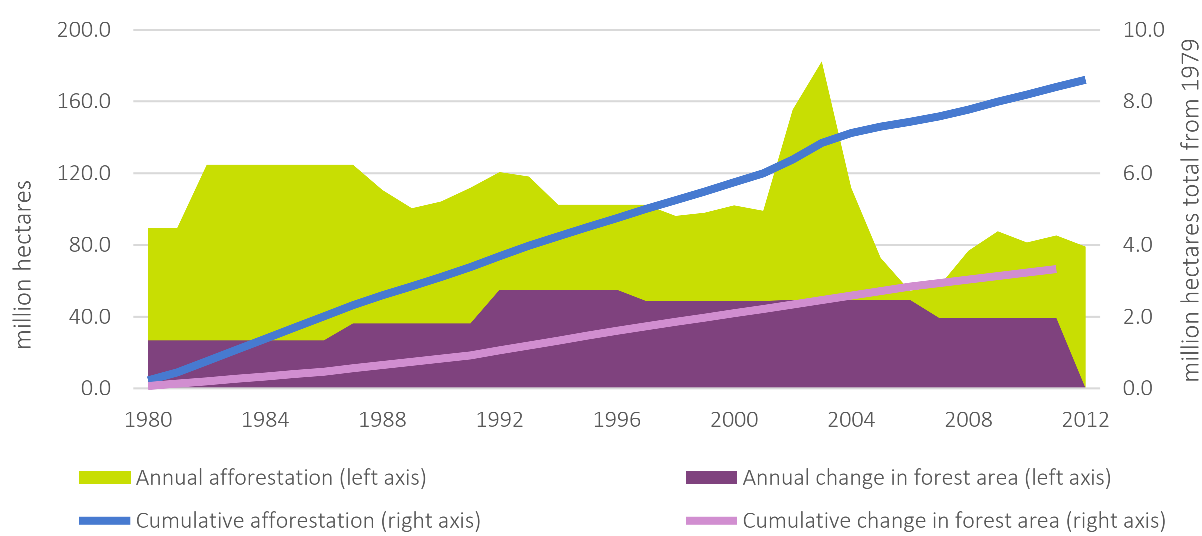
[58] FRA 2015.

[59] FRA 2015. The comparable 1986-2011 estimate using China's definitions and adjusting for the cover threshold change would be about 57 Mha increase (2.29 Mha $y^{-1}$).

Notes for Figure 5: *FRIC*: Data points are represented at the midpoint of each inventory period following China's convention in reporting to FAO. China's Forest Resources Inventories use a tree cover definition of forest area using a 30% threshold before 1994 shifting to 20% after; both were reported for Inventory IV from 1989-1993, with 11.5 Mha more forest area using a 20% cover threshold. Zhang and Song (2006) is the data source prior to Inventory III (1984-1988). *Liu and Tian:* This series uses a consistent 30% cover threshold. *FAO 2014:* China's reports to the FAO apply a land-use definition, including denuded areas that are expected to regrow, as well as areas with forest cover between 10% and 20%. The 2015 estimate reported in FRA2015 was a simple linear interpolation from 2005-2010 and is not included in this figure.

Comprehensive and independent assessments of China's recent forest area history are rare,[60] and those that are available show mixed agreement with Government statistics. Hansen et al's (2013) satellite-based total tree cover estimate for China at 20% cover threshold in 2000 is 175.5 Mha, in very close agreement with China's 1999-2003 inventory estimate of 175 Mha. Hansen et al (2013) show tree cover losses averaging 453,000 ha $y^{-1}$ from 2001-2014 and increasing over the period, compared to an average annual tree cover gain of only 187,000 ha $y^{-1}$ for 2001-2012 (at a 50% cover threshold for gains). However, there are indications that the Hansen et al (2013) data may underestimate forest area gains, especially for countries with significant forest plantations, so the implied net forest area decline from this source is noted but does not provide strong evidence that government statistics are incorrect. An independent analysis (Liu et al, 2005) of Landsat-TM/ETM images from 1990 to 2000 also shows area decreases – although very slight – for both the broad class of woodlands (-0.48%, from 227.8 Mha to 226.7 Mha) and for the subset of woodlands that meet a 30% tree cover threshold (-0.52%, from 138.3 Mha to 137.6 Mha), also drawing into some question the officially reported statistics. Viña et al (2016) assess China's forest cover changes between 2000 and 2010 using medium spatial-resolution surface reflectance data from NASA's MODIS, and find that 1.6% of China's territory (about 15.7 Mha) displayed a significant gain in percent tree cover, while only 0.38% (about 3.7 Mha) experienced a significant loss.[61] This result supports the conclusion that China's forest area has increased, although it suggests a slower rate of increase than government-reported data. It is important to note that each of these comparisons is imperfect, suggesting the need for additional independent verification of China's forest inventory data.

## Figure 6. Afforestation vs Forest Area Change 1980-Present

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[60] See below for independent assessments of carbon stocks. While national assessments are rare, some remote sensing studies of China's sub-regions are available, for example Xiao (2014) which shows tree cover trending upward in the Loess Plateau (6.7% of China's land area) from just under 8% in 2000 to just over 10% in 2000.

[61] MODIS bands have spatial resolution ranging from 250m to 1km, with pixels at least 100 times larger than China's 1/15th hectare area limit used for defining forest. Note that the results of Viña et al (2016) – a proportion of China's total land area that experienced increased vs. decreased forest cover – cannot be plotted in Figure 5.

Notes for Figure 6: This figure uses China's forest area definitions, based on forest cover rather than land use. Annual and cumulative forest area change are corrected for China's change in forest cover threshold from 30% to 20%. Annual afforestation is listed in China's FRA 2015 report for 1988-1992 and 1998-2012. Estimates for 1993-1997 and prior to 1988 are annualized from NFI totals reported in Zhang and Song (2006).

China's inventories reveal afforestation efforts of a scale more than double the actual forest area change. Figure 6 compares the total afforestation with the change in forest area since 1980, on both an annual and cumulative basis. The cumulative afforestation area over this period of 170 Mha exceeds the change in reported forest area over the period (66.5 Mha) by a factor of 2.5. This difference is likely the result of some combination of planting or seeding failures, afforestation of previously afforested areas, and afforestation of areas that have not yet reached a 20% cover threshold and appeared in forest area statistics.

As noted above, China's A/R/R efforts include additional action beyond afforestation. China reported to FAO areas of hillside enclosures on "non-standing trees land and open land" and on shrub land. During the six years 2007-2012, which is the only period available with complete data for all categories, China reported 37.8 Mha of forestation effort including 23.4 Mha (62%) of afforestation by planting/seeding or air seeding, 9.7 Mha (26%) of hillside enclosures on open land, 2 Mha (5%) of hillside enclosures on shrubland, 2.1 Mha (6%) of "slash regeneration" (reforestation), and 0.7 Mha (2%) of "afforestation under existing tree canopies" (restoration). If China's efforts to promote tree regeneration through hillside enclosures were included, it would yield a ratio of "afforestation effort" to forest area change that is substantially higher, i.e. it takes more effort for every hectare of forest area change.

China included an objective to expand forest area by 40 Mha from 2005 to 2020 (2.67 Mha $y^{-1}$) as one of several "nationally appropriate mitigation actions" in its 2009 Copenhagen Accord submission, which it reconfirmed in its 2016 Nationally Determined Contribution. China's NFI data as reported to FAO suggests an expansion rate of about 2.11 Mha $y^{-1}$ during the years 2005 through 2011[62] for all forests including economic and bamboo forests, and a rate of increase of about 1.72 Mha $y^{-1}$ using FAO forest definitions. However, China reported in its 2016 NDC an increase in forested area of 21.6 Mha from 2005-2014, an average rate of increase of 2.4 Mha $y^{-1}$ and close to what would be needed to achieve the 2020 target.[63] Presumably, China's commitments should be interpreted using its own forest definitions and data, suggesting that additional expansion is needed to achieve the 2020 target, beyond that reported through 2011 to the FAO or reported through 2014 to the UNFCCC.

About 55% of China's forest expansion has been in the form of plantations with the remaining 45% from natural forest expansion. Plantation area expanded from near zero in 1950 to about 28 Mha in 1986, further expanding by another 36.5 Mha (1.46 Mha $y^{-1}$) to over 64 Mha in 2011. Natural forest area declined until protections were put in place in 1978, at which point it recovered significantly.[64] From 1986 to 2011, natural forest area expanded by about 30 Mha (1.21 Mha $y^{-1}$). Not surprisingly, this observed ratio of plantation forest to natural forest expansion (55% to 45%) is about the same as the FAO-reported breakdown of forest expansion between natural regeneration and afforestation.

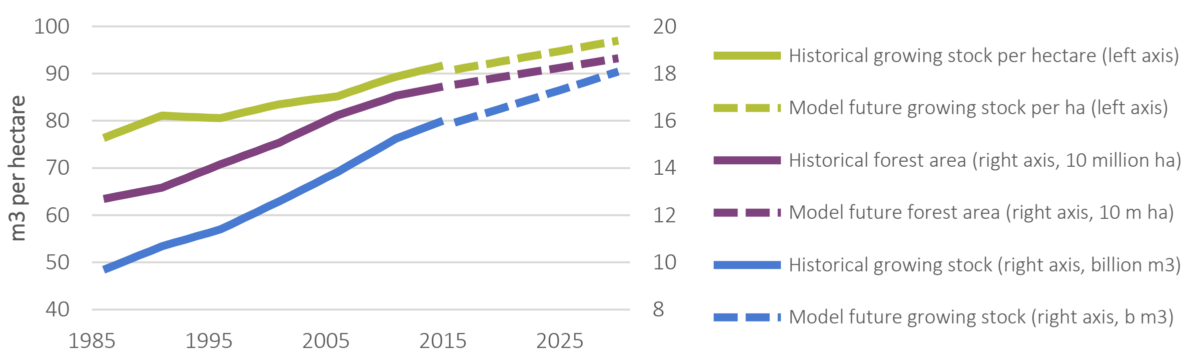
[62] China reports forest area values from each NFI for the midpoint year of the Inventory – e.g., the forest area figures from the 8th NFI, representing 2009-2013, is reported as the 2011 value to FAO. Intervening years are interpolated, and 2015 estimates are forecast.
[63] It is not clear why the value reported in the NDC is higher than that reported to the FAO. It is possible that new data from ongoing 9th NFI was used for the NDC. However, China's forecast of 2015 forest area in its 2014 report to the FAO would suggest a decline in annual forest area gain rather than an increase in the rate of change, resulting in a 2005-2014 average rate of 1.87 Mha $y^{-1}$.
[64] Zhang and Song 2006.

## Carbon Mitigation Impacts

China has highlighted its afforestation programs as climate mitigation policy in its reports to the UNFCCC, for example describing the Grain for Green Program payments in its Second National Communication and highlighting the achievement of 27.7 Mha of new forests and increase of forest cover in the project areas by more than 3% (PRC 2012).[65] It has also set significant carbon-related forest-sector goals in the UNFCCC. At the Copenhagen COP in 2009 it made a pledge to increase forest stock volume by 1.3 billion $m^3$ from 2005 levels by 2020 (which translates into a total forest sink of about 2.4 $GtCO_2$).[66] China committed in its Paris NDC to extend and expand this goal to 4.5 billion $m^3$ over 2005 levels by 2030 (translating into 8.25 $GtCO_2$, an average of 330 $MtCO_2$ $y^{-1}$ for 25 years).

China has reported steadily increasing forest growing stock volume since the late 1980s, as growth has exceeded harvested volume in every inventory since the 4th NFI (1989-1993). Volume increases have been the result of both forest area expansion and increasing stocking rates as planted forests have matured and natural forests recovered – with average growing stock per hectare growing as well as absolute growing stock. According to China's reports to the FAO, the Copenhagen commitment of 1.3 billion $m^3$ increase in growing stock over 2005 levels was surpassed before the end of 2010 (Figure 7). China's NDC submitted in March 2016 reported that growing stock volume had increased by 2.188 billion $m^3$ over 2005 levels by 2014. Both sources suggest an average increase in growing stock of about 242 million $m^3$ $y^{-1}$. At this rate of change, China's NDC goal of 4.5 billion $m^3$ over 2005 levels will be met by 2024, and exceeding an increase of 6 billion $m^3$ by 2030. This is not to suggest that maintaining recent historical rates of increase in stocking is trivial – it would require a continuation of extensive afforestation and forest protection efforts to meet the NDC goals. For example, a linear projection through 2030 of growing stock per hectare shows that a 4.5 billion $m^3$ increase in total growing stock from 2005 would require continued forest area expansion of about 12 million ha, or 800,000 ha $y^{-1}$, less than half the average forest area change of 1.75 million ha $y^{-1}$ from 1990-2015, but still quite significant.[67] This would be a significant proportion of the remaining potential identified by China in reports to the FAO (2014): 39.6 Mha of "forest suitable land" was available in 2011, down from 82 Mha in 1986 and 69.6 Mha in 1991.

### Figure 7. Historical and potential future growing stock




Notes: Area and stock in this figure include arbor forests (over 20% cover) and open forests (between 10% and 20% cover), but exclude economic forests (such as orchards) and unstocked forests such as recently harvested or burned areas. Based on FRA2015 data. Less than 0.7% of stock is in open forests. Projections based on a linear fit of the 1990-2015 growing stock per hectare.

[65] The NC2 provided estimates of forest land area in 2005 of 284.93 Mha (including both forests and woodlands) and forest area in 2008 of 195.45 Mha, consistent with forest area estimates reported by PRC in other contexts.

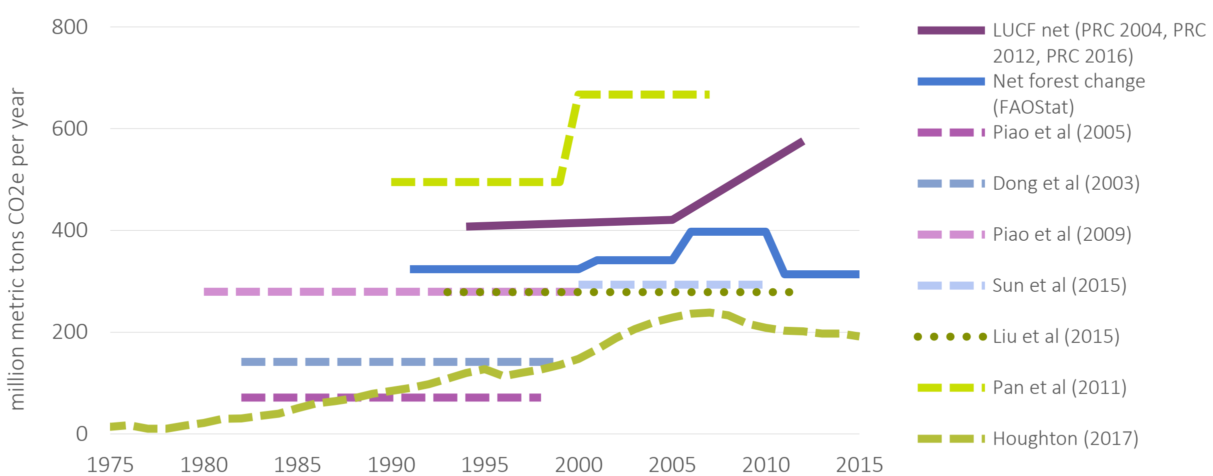
[66] Calculated at 0.5 tC/$m^3$ growing stock.

[67] If average stocking rate increases on existing forest lands slows rather than continues along a linear trend, then meeting a 4.5 billion $m^3$ NDC commitment would require a larger expansion of forest area, but still less than the 1990 to 2015 average.

There is strong agreement among government data sources that China's forests have been a carbon sink of 340-580 $MtCO_2e$ per year in recent decades. GHG fluxes from land use change and forestry (LUCF) in 2012 were dominated by a forest sink of 597.5 $MtCO_2$, with some offsetting emissions from harvesting and conversion resulting in a net LUCF sink of 575.8 $MtCO_2e$ (PRC 2016, BUR). This was a larger net sink than the 420.8 $MtCO_2e$ reported for 2005 (PRC 2012), the result of large decreases in forest conversion and harvesting that more than compensated for some decrease in sequestrations from 2005 to 2012. The net sink reported in the First National Communication for 1994 was similar (407.5 $MtCO_2e$) (PRC 2004). Net forest sinks estimated by FAOStat from country reports are of a similar scale, averaging 343 $MtCO_2$ from 1991-2012.[68]

Estimates of the overall strength of China's forest carbon sink from the academic literature range from lower to about in line with government estimates (Figure 8). Piao et al (2005) estimate carbon sinks by integrating inventory data on area changes with satellite-based carbon stock estimates from NOAA/AVHRR NDVI products, finding a net forest carbon sink of 71.4 $MtCO_2$ per year between the early 1980s and the late 1990s. Other estimates based on inventory data have been higher, for example Dong et al (2003) estimate 141.6 $MtCO_2\ y^{-1}$ average for 1982-1999. Piao et al (2009) estimate the carbon balance of China's terrestrial ecosystems with just three forest components (vegetation, soils, and fire) totaling 279.4 (+/-142.3) $MtCO_2\ y^{-1}$ from about 1980 to 2000. Sun et al (2015) combine inventory data with MODIS data and an empirical statistical model to estimate a carbon sequestration rate in the 2000s of 293.3 (+/-378) $MtCO_2\ y^{-1}$. Houghton and Nassikas (2017) apply a bookkeeping approach to data reported by China to the FAO, finding a sink that increased steadily from the 1970s to a peak of 238.5 $MtCO_2\ y^{-1}$ in 2007, then decreased by 20% to 2015.[69] Liu et al (2015) use an estimate that is completely independent of government inventories, finding a sequestration from 1993 to 2012 of 278.7 (+/-36.7) $MtCO_2\ y^{-1}$. At the higher end of published studies, Pan et al (2011) estimate China's forest biomass sink using inventory data and a bookkeeping model to be 220 $MtCO_2\ y^{-1}$ from 1990-1999 and 422 $MtCO_2\ y^{-1}$ from 2000-2007, a value that is similar to the government's UNFCCC-reported value for 2005.

Figure 8. China's forest and land sink




Notes: Direct government estimates by PRC are represented by solid lines. Estimates that combine China's Forest Resources Inventories with field or remote sensing data on carbon are represented by dashed line. Only one estimate is available that relies only on remote sensing (dotted).

[68] LUCF as reported to the UNFCCC by China included carbon sequestration in shrub lands and bamboo forests as well as emissions from forest fires which are not included in the FAO's net forest conversion emissions estimate, explaining most of the discrepancy.

[69] Houghton, R.A., and A.A. Nassikas (2017). Global and regional fluxes of carbon from land use and land cover change 1850–2015, Global Biogeochemical Cycles 31:456-472, doi:10.1002/2016GB005546. Country-level data were developed in the article cited (but unpublished). Estimate includes all land use change and forest emissions.

Regardless of some differences, and the fact that government reported estimates appear higher than most estimates from the academic literature, it is clear that both government estimates and independent studies confirm a large and persistent forest carbon sink over the last three decades in China. The size of China's sink appears to have increased from the 1990s to the 2000s across most studies and government reports, with two sources suggesting a recent dropoff.

China's forest sink is likely to remain significant in the coming decades. Xu et al (2010) modeled China's future carbon sequestration based on forest age structure observed in the Forest Resources Inventories, assumptions about future forest growth and plans for afforestation. They expect an average carbon sink of 513 $MtCO_2\ y^{-1}$ for the period 2000-2050, about 60% of which would come from stock increases on existing forest areas as of 2003 and 40% would result from afforestation after 2003. With continued increases in growing stock per hectare, and additional afforestation of 800,000 ha $y^{-1}$ (as in Figure 8), sequestrations would be lower, but still significant – averaging about 250 $MtCO_2\ y^{-1}$ from 2016-2030.

## Summary and Lessons Learned: China Case Study

The scale, variety, and long history of China's forestation belie any attempt to draw simple conclusions. Between 1978 and 2012, China planted or seeded between 176-188 Mha of forest (a planting rate of over 5 Mha $y^{-1}$), enclosed hillsides to encourage natural recovery, reforested significant areas of cut-over and burned forests, and planted and seeded in areas already with tree cover (restoration). Altogether, these A/R/R actions have resulted in an increase of forest area by about 66.5 Mha (over 50% of starting forest area) at an expansion rate of over 2 Mha $y^{-1}$. Growing stock volume increased by 5.6 billion $m^3$ from 1986 to 2011, or 222 million $m^3$ per year. Net forest sequestrations were 8.54 $GtCO_2$ from 1994-2012, reaching a rate of 576 $MtCO_2\ y^{-1}$ in 2012, offsetting 5.8% of China's 2012 emissions from other sectors.[70]

Several notable factors affected China's successes and failures:

A clear motivation—unrelated to climate change—was present and urgent. For example, acute flooding, sedimentation, and an air quality crises in the late 1980s and 1990s were clear motivating factors for A/R/R efforts on the Loess Plateau.[71] In addition, a slow-moving food security crisis of declining soil productivity and agricultural land abandonment spurred dramatic action in the launch of China's "Six Key Forestry Programs." Earlier efforts to establish China's "Great Green Wall" through shelterbelt planting, motivated by the threat of an advancing Gobi desert, may in retrospect be viewed as less extensive in part because of the more diffuse and less immediate nature of the motivating threat.

Government capacity was also a critical enabling condition. The Chinese forestation programs were clearly successful in terms of mobilizing on-the-ground capacity and resources. The Chinese government supported implementation across wide swaths of the country with large-scale investment of national budget and human resources. The State Forestry Administration developed significant knowledge and technical design capacity and disseminated these broadly to local implementers through a vast network of offices. Mobilization was also advanced by the wide availability of inexpensive labor in rural areas. Policymakers had the capacity to prohibit overgrazing and provide substitute food and fodder.

Economic incentives and land security have also played a role. For example, changes in land rights provided additional tenure security and encouraged greater economic investment in long-term productivity. On the other hand, short time-horizon 'payment for ecosystem services' may have resulted in reversals of afforestation of some agricultural areas when payments ceased.

[70] See Annex 3 for a summary of China's efforts.
[71] Buckingham and Hanson 2015.

From 2000 to 2009, the total budgetary cost of China's Six Key Forestry Programs was about USD 113 billion. The cost of A/R over this period was about USD 2151-2317 per ha, or about USD 25.60 per $tCO_2$ of sequestration over the same period.[72]

Basic ecological conditions for success were lacking in many places with respect to the planned "afforestation" actions: attempts to plant thirsty tree species in areas that were not suited for them yielded significant failures. There is a need for well-defined goals and an implementation strategy that are in balance with the local environment. Mono-species plantations and low-diversity forests as an afforestation strategy may be appropriate if the goals are only to provide wood and a windbreak in areas with sufficient rainfall. But a different approach might be needed if annual rainfall is low, if storms and runoff erosion is a problem, if non-timber forest products and species diversity are also valued, or if less-active management and self-sustaining ecosystems are an objective.

The study of China's forest and climate reporting in service of an assessment of its forestation efforts suggests a few additional lessons learned regarding forest information and data strengths and gaps:

- China's detailed reporting that makes key distinctions between different forest activities is valuable. Other countries seeking to set and achieve extensive forest expansion goals might do well to emulate such data collection and reporting: separating out planting area by previous land status or use (e.g., tracking "slash regeneration" as distinct from seeding/planting of areas not previously forested); making a distinction between forest expansion efforts by planting/seeding vs. by natural regeneration; and reporting areas of land that are actively being afforested through planting/seeding or through enclosures/exclusions, prior to these areas being recategorized as "forest" when meeting definitional thresholds.
- China's tracking of forest area and status based on cover definitions of forest rather than land use definitions reveals dynamics (and evidence of significant policy-based action) that are obscured by land-use based forest reporting. For example, China's cover-based forest area inventories are much easier to compare with remote-sensing data.
- A strong and consistent national forest inventory program provides invaluable data for national-scale reporting and evaluations of success.
- Specific tracking and reporting of the end-state of afforested areas, or perhaps of the status of such areas at 5-year intervals after planting, would increase the ability to understand the effort needed to achieve a particular amount of forest expansion (and thus carbon sequestration). Even with very extensive data on both land-cover and land-use, it is difficult to fully explain the large differences between reported afforestation area and annual change in total forest area. While this difference is likely a combination of a) planting/seeding failures, either at the time of establishment or subsequent failure to protect seedlings from grazing or fire, b) planting/seeding of areas already considered forests (enhancing stocks), and/or c) incorrect categorization of action on recently harvested areas as planting/seeding for afforestation, it is not possible to estimate the proportions of reported afforestation area in these categories.
- It would be helpful to further understand and explain discrepancies between inventory-based forest area and change estimates and independent remote-sensing based estimates. China would be well-served by undertaking an effort to reconcile these differences.

[72] All estimates in real 2016 USD. Range per hectare is from including both afforestation and slash regeneration (A/R), to just including afforestation.

# India: A Recent Forest Turnaround and Growing Forest Agenda

Like many of the world's tropical forests, those in India experienced a long decline throughout the 18th and 19th centuries and well into the 20th century. About 45% of forests were cleared between 1700 and 1970, with forest area declining from near 120 Mha to around 65 Mha, and remaining forests increasingly degraded. Forest loss accelerated somewhat in the early 20th century as India's population grew. Carbon density in forests in many regions declined by 25 to 50% between 1930 and 1985 (Richards and Flint 1994). Drivers of loss and degradation included shifting cultivation and unclear tenure systems in the northern regions, direct conversion to agriculture in central India, growing demand for timber and wood fuel, and simple over-utilization by India's largely agrarian economy.[73]

After India's independence from British colonization, the emphasis on forests as a biomass resource for the agricultural sector continued, although a shift began to emerge towards classifying and managing forests according to a broader set of uses in India's 1952 forest policy – including protection forests, national forests, village forests and tree lands. This earliest National Forest Policy set an ambitious goal of eventually bringing 33% of the country's land under forest cover, an increase from the 23-24% cover at the time.[74] A 1972 Wildlife (Protection) Act set up an extensive network of protected areas, covering for nearly 14 Mha of forests by the end of the 1980s. In the mid-1970s, a new grassroots environmental movement began to spread in the northern regions (the "*Chipko*" movement), seeking in part to shift away from the timber-resourcing focus of national forest policy towards a greater recognition of local and community uses. The "social forestry movement" of the time sought to shift control of forest resources to local communities while encouraging forest planning and management to provide fuel and biomass through dedicated plantations, with poor initial results. By most accounts forest cover continued to decline. A Forest Conservation Act was enacted in 1980 to slow conversion of forests, requiring among other measures that states seek approval by the central government for any forest diversions.[75]

By the late 1970s and early 1980s, with failures of early forest conservation programs evident, the Government began to shift forestation policy in two directions. Firstly, a growing recognition of severe degradation in large swaths of former forest land and subsistence agricultural lands, and the impacts of this degradation on soil conservation, watershed functioning and downstream agriculture,[76] led to a new policy focus on large-scale afforestation. Afforestation efforts expanded dramatically in the 1980s, from 240,000 ha $y^{-1}$ achieved from 1974-1979, to 930,000 ha $y^{-1}$ from 1980-1985. A major 1988 revision to the National Forest Policy reinstated the 1952 policy's forest expansion goal for India to reach 33% forest cover, even though intervening decades had seen a decline rather than expansion of forests. By the late 1980s, afforestation efforts had grown to over 1.7 Mha $y^{-1}$ (1985-1990).[77]

The second major policy shift in the 1980s was a focus on community forest management and local involvement in afforestation and forest restoration. An Integrated Wasteland Development Program was set up from 1989-1990 under the Ministry of Rural Development to promote cooperative afforestation of community and private lands, ultimately expanding to include restoration of degraded forestlands as well as afforestation. The Ministry of Environment and Forests (MoEF) simultaneously launched an Integrated Afforestation and Eco-Development Program with similar objectives for the land under its control, also emphasing partnerships with local communities. The cooperative approach was implemented across all

[73] Damodaran and Engel 2003; FSI 1987
[74] "Trees outside forests" appear to be included in the target (FSI 2015, Tree Cover Chapter, http://fsi.nic.in/isfr-2015/isfr-2015-tree-cover.pdf).
[75] Damodaran and Engel 2003.
[76] Gray and Srinidhi 2013; Damodaran and Engel 2003.
[77] Ninth Five-Year Plan, 1997.

agencies in 1990 through a "Joint Forest Management" (JFM) policy circular for implementing the 1988 National Forest Policy.

The emphasis on community involvement and the simultaneous elevation of ecosystem and economic health objectives has continued in more recent efforts. These include the 2002 MoEF National Afforestation Programme (NAP), which supported afforestation through a combination of state and national programs, and the 2005 Mahatma Gandhi National Rural Employment Guarantee Scheme which guaranteed 100 days of employment for the rural poor and included tree planting as a subsidized action.[78] The NAP goals for 2002-2007 included 3 Mha of afforestation and reforestation, and 20 Mha of forest and land rehabilitation.[79] A Compensatory Afforestation Fund and Planning Authority (CAMPA) was established largely as a state program in 2004 to manage the use of funds levied on deforestation under the Forest Conservation Act, for the purpose of establishing forests for communities that lose forest access through, for example, dam construction.[80] However, very little of the CAMPA money was accessed, and Parliament passed a bill in 2016 to more quickly distribute more than 400 billion rupees (about USD 6 billion) that had accumulated in the fund.[81]

In 2008, when the Prime Minister released India's National Action Plan on Climate Change (NAPCC), the climate objectives of India's forestation programs were further institutionalized. The Green India Mission (GIM), one of eight missions under the NAPCC, aimed to enhance carbon stocks on 10 Mha over 10 years (2010-2020) by increasing forest and tree cover on 5 Mha and improving forest quality on another 5 Mha, together expected to enhance forest sequestration by 50 to 60 $MtCO_2e\ y^{-1}$ by 2020[82] and about 100 $MtCO_2e\ y^{-1}$ in 2030.[83] The program was initially allocated 60 billion rupees (about USD 1.37 billion in 2008),[84] expanding to 440 billion rupees (USD 7.2 billion) by 2014[85] – about USD 720 per hectare. The GIM absorbed the NAP starting in 2012. While the GIM was advanced through the NAPCC and thus approached forests firstly as a carbon mitigation tool, it maintained a framing of forests and REDD+ as providing an opportunity for both carbon and non-carbon benefits including the advancement of local community rights and economic interests.[86]

In 2014, India introduced the world's largest forest-cover based funding mechanism, in recognition of the complexities of successful forest management, the ecological and climate benefits provided by forests, and the opportunity cost of preventing forest conversion. The apolitical India Finance Commission increased the overall proportion of Central tax revenue devolved directly to the states from 32% to 42%, and changed the formula for allocating that revenue between states.[87] The new formula bases 7.5% of the total state allocation – about USD 6 billion out of USD 80 billion in the 2015-2016 fiscal year – on state-level total dense forest cover as monitored by the Forest Survey of India.[88] Based on the forest cover from FSI 2013, this works out to about USD 150 per hectare.[89]

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[78] Program evaluations such as Dutta et al 2014 have found that MGNREGA has not come close to meeting its employment guarantee objectives.
[79] BUR 2015.
[80] At least one case study found that local communities were not made whole by compensatory afforestation that replaced 13,000 hectares of natural forests inundated by the Sardar Sarovar Dam with 13,000 hectares of tree planting of monoculture plantations, many of which failed, or by natural planting in different ecological zones that didn't satisfy community needs.
[81] Compensatory Afforestation Fund Bill, 2016. http://pib.nic.in/newsite/mbErel.aspx?relid=147937
[82] National Mission for a Green India, 2010.
[83] NDC 2016, Section 1.6.
[84] National Action Plan on Climate Change, 2008, [link]. Conversion at 1:43.7 USD:Rp, the 2008 average. Equivalent to USD 1.58 billion in 2016.
[85] Cited by the Planning Commission Expert Group on Low-Carbon Growth, Final Report 2014. Equivalent to USD 7.4 billion in 2016.
[86] Vijge and Gupta, 2014.
[87] Report of the 14th Finance Commission. http://mof.gov.in/14fincomm/14fcreng.pdf
[88] Jonah Busch. 2/27/2015. "India's big climate move." https://www.cgdev.org/blog/indias-big-climate-move
[89] FSI 2013 reports 40.2 Mha of dense and very dense forest cover total in India. http://fsi.nic.in/cover_2013/sfr_forest_cover.pdf

In its Paris Agreement submission, forestation was further elevated by India: a goal "to create an additional carbon sink of 2.5 to 3 billion tonnes of $CO_2$ equivalent through additional forest and tree cover by 2030" was one of only three quantified targets by India.[90] India's NDC highlighted several of the above programs as key strategies for achieving planned afforestation, including the USD 6 billion or more per year of forest cover based tax devolution, another USD 6 billion total of CAMPA funds allocated in 2016, the NAP, JFM, REDD-Plus policy, and the National Agroforestry Policy.[91]

One final institutional champion for India's afforestation strategy and goals is worth highlighting here. Prior to developing India's Twelfth Five-Year Plan, the Planning Commission (since dissolved) empanelled an Expert Group on Low Carbon Strategies, consisting of outside experts and joined by representatives of the relevant government agencies, to assess options and propose an action plan for India to achieve a low carbon development pathway. The group's 2014 report included a detailed assessment of sequestration potential and a set of options for enhancing carbon sequestration in the forestry sector by 92.3 $MtCO_2e$ per year by 2023, estimated to cost 114 billion rupees per year (USD 1.87 billion)[92] or about $20/$tCO_2e$. The forest sector recommendations of the Low Carbon Strategy are particularly notable because India's Biennial Update Report to the UNFCCC included most of them in a table of forestry sector mitigation actions.[93] Also listed by the same BUR table are CDM afforestation and reforestation projects with total lifetime mitigation potential of 10.9 $MtCO_2$; voluntary AFOLU carbon market projects; and pilot REDD+ projects progressing through a range of support mechanisms. See Annex Table 1 for a summary of the above afforestation-related programs, their objectives, and their implementing agencies. Table 2 summarizes concrete A/R/R targets for relevant programs.

Table 3. India's Afforestation and Forest Restoration Targets[94]

| | Afforestation and Reforestation | Rehabilitation and Improved Tree Cover | Time Period |
|---|---|---|---|
| National Forest Policy | Bring 33% of India's land under forest cover. | | Not time-bound |
| National Afforestation Programme | 3 Mha total<br>600,000 ha $y^{-1}$ | ~20 Mha total<br>~4 Mha $y^{-1}$ | 2002-2007 |
| Green India Mission | 5 Mha total<br>500,000 ha $y^{-1}$ | 5 Mha total<br>500,000 ha $y^{-1}$ | 2010-2020 |
| Low Carbon Strategy | 1.7 Mha $y^{-1}$ | 2 Mha $y^{-1}$ | by 2023 |

[90] Also included were an emissions intensity of GDP target of 33 to 35% below 2005 by 2030, and a 40% renewable electric power installed capacity target by 2030, as well as five unquantified planning, capacity, and investment goals.

[91] NDC (2016) Section 1.6. India's National Agroforestry Policy, passed in 2014, seeks to encourage agroforestry, in particular by addressing adverse policies and lack of institutional finance. The policy tasked the Ministry of Agriculture with developing a strategy to achieve these objectives. http://vikaspedia.in/agriculture/policies-and-schemes/crops-related/national-agroforestry-policy

[92] At 2014 average exchange rate of 1:61 USD:Rp.

[93] BUR (2015), Table 3.11.

[94] Goals as cited in BUR (2015).

## Forest Definitions and A/R/R in the Indian Context

India's National Forest Inventory defines "forest cover" as "all lands, more than one hectare in area, with a tree canopy density of more than 10%," noting that such lands may not be officially recorded as forests in Government records. India makes a further distinction between open forests (10-40% canopy density), dense forests (40-70%), very dense forests (over 70%), and mangroves. Areas with tree cover less than 10% are classified as scrub. The NFI also collects data on "trees outside forests" (tree cover outside areas legally recorded as forest) and its subset "tree cover" (patches of trees less than one hectare of extent). The NFI's "tree cover" areas are monitored based on ground surveys rather than satellite-based forest cover assessments, which use a one ha minimum mapping unit.[95]

India makes little distinction in the domestic context between afforestation, reforestation, and forest restoration, with the term "afforestation" often used as an umbrella term that encompasses a wide range of efforts to establish trees both in and out of forests. For example, the National Afforestation Programme has as its goal more than just "afforestation" as typically defined: to "increase and/or improve forest and tree cover." Among its primary outputs and activities are a broad range of actions that are not afforestation as defined in this paper, but rather reforestation, restoration, natural regeneration, and promotion of trees more generally, for example pursuing improved natural forest stock through assisted natural regeneration of degraded areas, and promoting tree cover in non-forest areas through agro-forestry on shifting cultivation lands and other farmlands.[96] The Green India Mission has as its first objective "increased forest/tree cover on 5 Mha of forest/non-forest lands and improved quality of forest cover on another 5 Mha," with sub-targets that include 1.5 Mha of improvement in moderately dense forests (which would be restoration) and 3 Mha in open degraded forests (a combination of restoration and reforestation).[97] However, "afforestation" is the dominant term used in reference to the objectives of both programs, as well as to the broader forest portfolio, for example in India's National Planning documents and in its reports to the UNFCCC.

India does not consistently track A/R/R area as part of its biennial NFI nor report on it consistently in the biennial "State of the Forest" reports. The agency responsible for implementing the National Afforestation Programme sets standardized "afforestation targets" for each state and compiles reported achievements towards those targets, which include the "area covered under plantation on public & forest lands" (meaning the area planted), and "seedlings planted."[98] There is no distinction in these reports between planting on already forested lands (restoration), on recently forested lands (reforestation), or on non-forest lands (afforestation).[99] These compiled data are reported to the FAO collectively as "afforestation," but India is careful to note that "the statistics on afforestation and reforestation are not separately maintained in India."[100]

When "afforestation" is used in the broad sense encompassing afforestation, reforestation, and restoration as defined in this paper, as India does in most contexts, it is put in quotation marks.

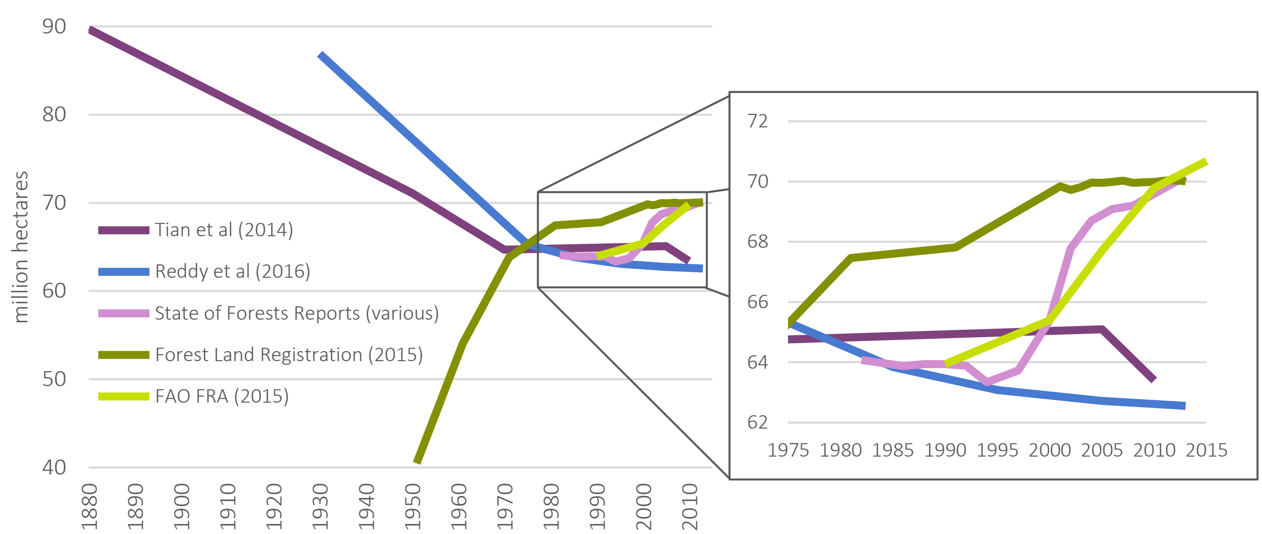
[95] The India State of Forest Report, 2015 reports a "tree cover" area of 9.26 Mha, 11.7% of the total forest cover plus tree cover of 79.4 Mha.
[96] Government of India, 2009.
[97] Government of India, 2010.
[98] A distinction is made between "actual area planted," defined in a footnote as "(block area (in ha) * number of seedlings planted)/650 seedlings" and "notional area planted," which is "calculated for scattered planting in schools/institutions (in less than 1 hectare area) and also along the roads/canal/railway line etc. by taking 650 seedlings planted equivalent to one ha of area covered."
[99] Afforestation under 20 Point Programme Brief Note. Available at: http://naeb.nic.in/progSchem.html
[100] India notes in its FAO reporting that "number of seedlings distributed" is converted to planted area assuming 2000 seedlings per ha.

## Forest Area History and Impacts

Long-term reconstructions[101] show that India's forest cover declined significantly from 1880 to 1970 or 1980 (Figure 9), with declines likely starting in 1700 or earlier. Tian et al. (2014) incorporate state- and province-level historical archives and recent remote-sensing land use data into a reconstruction showing a loss of 28% forest land use from 89.7 Mha in 1880 to 64.7 Mha in 1970, a brisk rate of loss of 0.36% per year. A more recent historical reconstruction also shows a 20th century decline starting in 1930, although with a higher area estimate and steeper rate of loss (Reddy et al 2016).

Two datasets provide forest area estimates from the Government of India prior to 1990. In 1987, the Forest Survey of India (FSI), an agency within the Ministry of Environment and Forests, began releasing its biennial "State of Forest Reports" incorporating both satellite imagery and field sampling and data collection. Forest cover in the first SFR was estimated at 64.08 Mha based on data collected from 1981-1983 (considered by India to represent forest area in 1982), very similar to most of the historical reconstructions. India's Ministry of Agriculture provides a second source of forest area estimates, based on a land use rather than tree cover definition, representing "land controlled by the forestry department"[102] collected from state and local land registration and administration and beginning in 1950-1951.[103] The rapid increase in forest land use from 1950 to 1980 is the result of extending legal and administrative classification to more areas with tree cover, not an expansion of tree cover.

**Figure 9. India's forest area**




Notes: a) The "Forest Land Registration" series is from India's Agricultural Statistics at a Glance 2015. This series is the only one that uses a land use rather than tree cover definition of forest.

While the long decline in forest area through the 1970s is clear, the pattern in subsequent decades is less so (Figure 9). Registered forest land increased substantially until about 2000, then stabilized at around 70 Mha (India Agricultural Statistics at a Glance, 2015). The Forest Survey of India's satellite-based forest

[101] Studies that estimate India's forest area prior to the first estimates by Forest Survey of India (1982).

[102] Ravindranath 1997.

[103] For the purpose of land use statistics, the Ministry of Agriculture defines "Forest Area" thusly: "This includes all land classified either as forest under any legal enactment, or administered as forest, whether State-owned or private, and whether wooded or maintained as potential forest land. The area of crops raised in the forest and grazing lands or areas open for grazing within the forests remain included under the 'forest area'." Land Use Statistics Concepts and Definitions. http://eands.dacnet.nic.in/LUS-2010-11/Concept.pdf

cover estimates are very stable at around 64 Mha from 1982 through 1992, with negligible declines of about 0.03% per year (19,400 ha $y^{-1}$). Forest cover then appears to decline rapidly for the two years from 1992 to 1994, climbing thereafter from the 1994 nadir of 63.3 Mha – slowly at first, then rapidly from 1997 to 2005 (at a rate of over 700,000 ha $y^{-1}$), then more slowly (~160,000 ha $y^{-1}$) through the most recent inventory's 2013 estimate. From 1994 to 2013, forest area expansion averaged 359,000 ha $y^{-1}$. Changes in satellite sensor, map scale, and interpretation method may have influenced this data series.[104] There have also been questions raised about the accuracy of India's FSI, with one FSI researcher arguing that forest cover is consistently over-estimated because of the satellite data's inability to detect smaller-scale and often illegal felling (Gilbert, 2012). India's submissions to FAO's Forest Resources Assessments have included the FSI's annual forest cover estimates as source data, although their approach of assigning survey years' values to FRA data points smooths some of the trend in the underlying data (Figure 9).

Two independent studies of India's recent forest cover show a decrease rather than increase in total forest cover. Tian et al (2014) estimates of forest area from 2005 to 2010 show a steep drop of 340,000 ha $y^{-1}$ (-0.53% $y^{-1}$) after a slight increase from 1970 to 2005 averaging 11,000 ha $y^{-1}$. Reddy et al (2016) visually interpreted forest cover and forest canopy density from an independent time series of satellite images for 1975-2013. Their analysis also suggests declining forest cover in India, with a more rapid decrease in early years that slows more recently, averaging a slow decline of 29,000 ha $y^{-1}$ (0.05% $y^{-1}$) from 1995-2013 when the official FSI data was showing an average gain of 360,000 ha $y^{-1}$. Both independent studies (Tian et al 2014, Reddy et al 2016) used a coarser spatial resolution for their satellite data analysis than the FSI, and a sampling rather than wall-to-wall analysis, which could explain some of the differences.[105]

Another comparison point is provided by Hansen et al (2013), which also paints a rather different picture of forest area and forest area change than official data. Year 2000 forest cover at a 10% threshold as estimated by Hansen is only 75% of the corresponding FSI estimate, although spatial resolution differences likely explain some of this difference. It is also possible to compare both gains and losses from Hansen at 50% cover threshold to the FSI data for dense and very dense forest cover (together representing a 40% cover threshold). Over the period 2000-2013, FSI shows a 1.5% increase in dense and very dense cover, from 39.52 Mha to 40.13 Mha, much smaller than the 16% increase in open forest cover. Hansen data at 50% cover show 30.45 Mha of forest cover in 2000, a gross loss of 825,000 ha of cover from 2000-2013, and a gain of about 276,000 ha over the same period, suggesting a net loss in dense and very dense forest cover of about 1.8% over the period – although the Hansen area gain product should be interpreted cautiously (as noted above). The inconsistency in the sign of recent forest area changes between India's official forest survey and all three of the identified independent studies is unresolved.

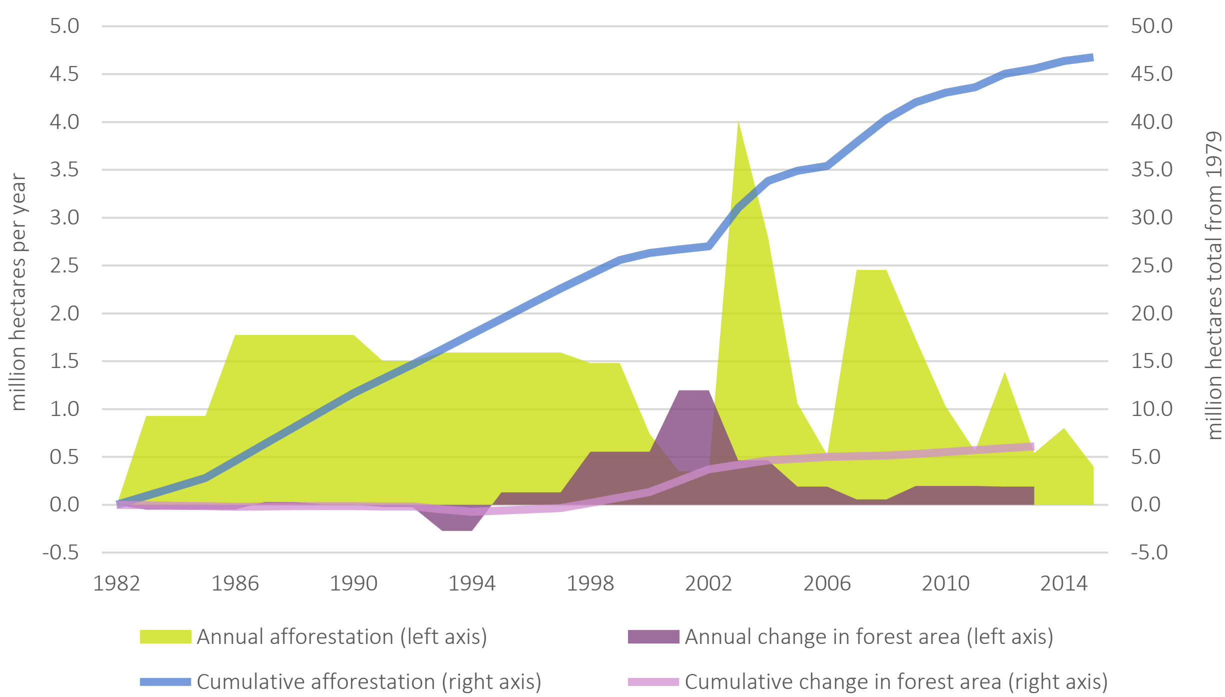
Several different government-based estimates of India's annual "afforestation" area are available, with most sources showing an average of 1 to 1.5 Mha $y^{-1}$ in recent decades. Total and cumulative "afforested area achieved" during each of India's Five-Year Plans (national centralized economic plans) since 1951 was first summarized in the Eighth Five-Year Plan for 1992-1997 and updated through the Tenth Plan (for 2002-2007) (Lal and Singh 2000, Kishwan et al 2007, Kant et al 2008, and Ravindranath et al 2008). "Afforestation" rates in official government statistic are estimated to be 1 Mha $y^{-1}$ or more; from 1981-1997, averaging around 1.4 Mha $y^{-1}$, and dropping to about 1.135 Mha $y^{-1}$ from 1998-2005 (Ravindranath

[104] For example, India shifted from visual to digital interpretation, which allowed the minimum mappable unit to drop from 25 hectares (500x500 m) to 1 hectare (100x100 m) from 1997 to 2000.The minimum mappable unit is the smallest area over which changes in tree cover are identified, dropping from about 15x15 pixels for visual interpretation to 4x4 pixels after the shift to full digital interpretation.
[105] The two studies use spatial sampling on a grids approximately 5 to 10 km on the side, based on both high- and medium-resolution data with spatial resolution ranging 20m (0.4 ha pixels) from SPOT-4 data in recent years to 250m (62.5 ha pixels) and up from MODIS in earlier years.

et al 2008). India reports two different sets of "afforestation" area estimates to the Forest Resources Assessment (FAO 2014) for 1990, 2000, 2005, and 2010. The reported values average 1.5 Mha $y^{-1}$ for the four reported years including both reported block plantations and area-equivalent plantings from distributed seedlings (assuming 1 ha for every 2000 seedlings), and 1.04 Mha $y^{-1}$ for just plantations. The most recent government-based estimates appear in India's BUR (2015) as "afforestation achieved under the National Afforestation Plan," averaging just over 1.5 Mha $y^{-1}$ from 2003 to 2015.

India's stated "afforestation" effort far exceeds the pace of forest cover expansion. India's forest cover expands by an average rate of just under 200,000 ha $y^{-1}$ from the first FSI estimate in 1982 to the last in 2013 (Figure 10), while India's claimed area of "afforestation" effort was more than 7.5 times more extensive than this, averaging 1.5 Mha $y^{-1}$ over the same period.[106] Over the period from 2001-2013, afforestation under the National Afforestation Plan was about 1.5 Mha $y^{-1}$ (BUR, 2015), while forest cover expanded about 368,000 ha $y^{-1}$, one-fourth as much. The large discrepancy between A/R/R effort and forest expansion provides additional evidence that a significant proportion of effort reported by India as "afforestation" is taking place in areas already identified as forest, and might better be considered reforestation, forest restoration or management. It is also likely that a) some "afforestation" does not lead to successful forest establishment; b) some of the "afforestation" effort reported is taking place outside of forests, through planting of single trees or small patches that do not result in a change in forest cover as defined by FSI's one hectare minimum mapping unit;[107] c) there might be more gross forest loss than is identified, with more "afforestation" effort compensating for forest cover loss rather than expanding forest area; and/or d) less "afforestation" action is taking place than reported.

Figure 10. Afforestation and net change in forest cover 1983-present




[106] "Afforestation" effort estimated from Ravindranath et al 2008 for 1983-2000 based on data from India's Five-Year Plans, and from estimates of total afforestation under the National Afforestation Plan from India's BUR (2015) for 2001-2015.

[107] If this were the case, one would expect increases in FSI estimates of the total area of such small forest patches (called "tree cover" by FSI, and first estimated for the year 2000). The FSI tree cover estimates from 2000 to 2013 show a statistically weak and small positive trend on the order of 34,000 ha $y^{-1}$.

It is difficult to assess whether India is on track to meet its forestation targets, and how much additional effort might be required in the future. Its reporting of a single umbrella category of "afforestation"[108] does not match the separate targets for "A/R" and for "rehabilitation and improved tree cover." Reported "afforestation" action from 2003 to 2015 of just over 1.5 Mha $y^{-1}$ (BUR, 2015) far exceeds the A/R targets of 600,000 ha $y^{-1}$ for the NAP from 2002-2007 and 500,000 ha $y^{-1}$ for GIM from 2010-2020; exceeds the GIM's combined 1 Mha $y^{-1}$ for all categories; but falls far short of the NAP's combined 4.6 Mha $y^{-1}$ goal for all categories. The targets recommended in the Low Carbon Strategy for post-2020 would require an aggressive increase of 250% from 1.5 Mha $y^{-1}$ to 3.7 Mha $y^{-1}$ of combined effort for all categories.

The cost of India's "afforestation" has been relatively low per hectare of reported effort. India's Five-Year Plan documents provide previous-period expenditures by program, compiled alongside area of effort by several researchers (e.g. Kant et al 2008). For the Sixth through Ninth FYP's (1981-2002), expenditures per hectare of reported effort ranged from about Rp 2000 to Rp 5250 nominal, corresponding roughly to USD 155-380 per hectare.[109] The Eleventh FYP documents expenditures of Rp 11.79-12.94 billion for the previous five years on the National Afforestation Programme and for all programs under the National Afforestation and Eco-Development Board (including the NAP) respectively.[110] With BUR-reported "afforestation" effort totalling 10.86 Mha from 2003-2007, this suggests a much lower expenditure of only Rp 1100-1200 (USD 30-32) per hectare. Even if all expenditures for watershed programs, forestry and wildlife programs, and afforestation programs are included in the calculation, the expenditure only totals USD 74 per hectare. For comparison, the Low Carbon Growth Expert Group estimated a cost of Rp 50,000 (USD 840) per hectare for afforestation, Rp 20,000 (USD 336) per hectare for enhancing stocks on existing forests, and Rp 10,000 (USD 168) per hectare for expanding forests around forest fringe villages.

## Carbon Mitigation Impacts of India's A/R/R

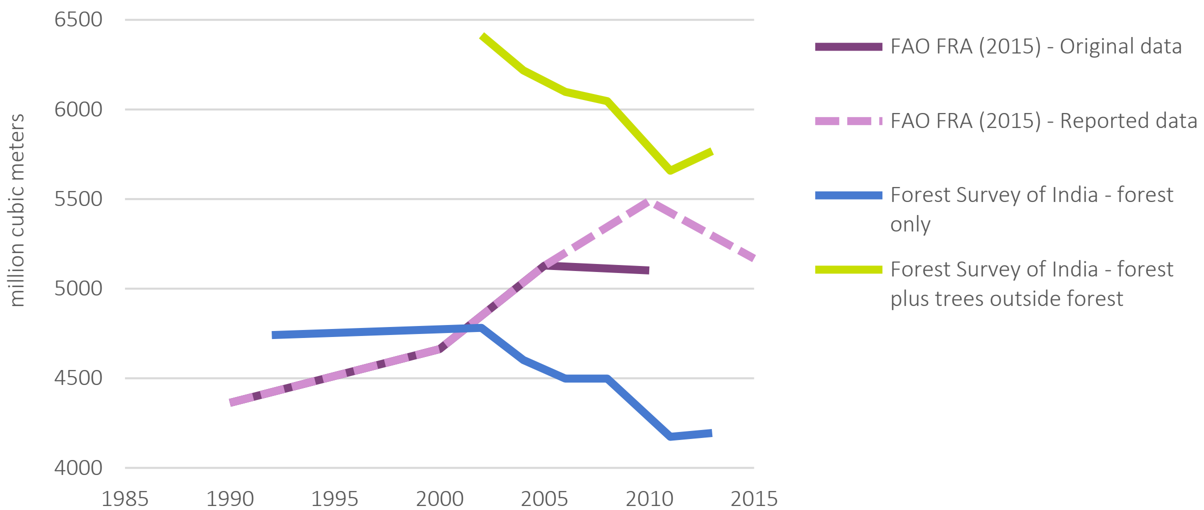
India's early A/R/R efforts were focused on soil conservation, production of timber, provisioning of fuel-wood and fodder, and urban tree cover. However, in the last decade "afforestation" has also been highlighted as a key climate mitigation tool by India in the context of its UNFCCC submissions. It was framed primarily as an adaptation tool in India's First National Communication to the UNFCCC (2000), while in the Second National Communication (2010) it was highlighted as both an adaptation and mitigation tool. The large increase in forest sink might explain this shift in framing: total LULUCF emissions as reported in NC1 for 1994 were positive, with forests only providing a small net sink of 5 $MtCO_2$, while LULUCF was reported as a large sink in 2000 the SNC (2010), mostly from forests, offsetting nearly 15% of other emissions. India had also in the interim advanced its National Action Plan on Climate Change, which included the National Mission on Green India (GIM) as one of eight related sectoral plans. In its Paris Agreement submission, A/R/R was further elevated: a goal "to create an additional carbon sink of 2.5 to 3 billion tonnes of $CO_2$ equivalent through additional forest and tree cover by 2030" was one of only three quantified targets by India.[111]

There is mixed information on the recent history of India's forest carbon stock changes. While most government data and some independent studies of forest fluxes indicate that forests were a net sink, forest growing stock volume as reported by the FSI follows a different pattern (Figure 11). Volume was basically stable from 1992-2002, then declined over the following decade by nearly 13% through 2011

[108] The BUR did not provide estimates of recent forest rehabilitation area, nor were such estimates found in other sources.
[109] This calculation uses period average Rp to USD exchange rates and USD GDP deflators to convert to 2016 real USD.
[110] Annexure 9.1 http://planningcommission.nic.in/plans/planrel/fiveyr/11th/11_v1/11th_vol1.pdf
[111] Also included were an emissions intensity of GDP target of 33 to 35% below 2005 by 2030, and a 40% renewable electric power installed capacity target by 2030, as well as five unquantified planning, capacity, and investment goals.

and stabilized from 2011-2013. Starting in 2002, the FSI also estimated growing stock volume for trees outside forests; the total growing stock volume for both forests and trees outside forests showed a similar 12% drop from 2002-2011, with a small 2% recovery from 2011-2013. These large decreases in wood volume from 2002-2011 would suggest that forests were a net source rather than sink, in contrast with India's carbon stock and emissions reporting. India reported a different pattern for growing stock volume to the FAO FRA (2015), with volumes increasing from 1990 through 2010, and declining thereafter in the reported series (Figure 11).

Figure 11. Growing stock volume




Notes: India's report to the FAO FRA (2015) includes two growing stock series: the "Original data" (section 3.2.3) with values through 2010, and the officially reported data (section 3.4). The notes suggest that the reported 2010 value includes growing stock in areas of trees outside forests, but no adjustment is made to earlier years, making it appear that growing stock increased from 1990 through 2010.

Estimates of India's forest and land $CO_2$ flux from the government or based on government-reported cover data generally show a strengthening sink from about 1990 to 2005 with some weakening in recent years. However, independent forest cover change data (Reddy et al 2016 and Sheikh et al 2011) suggest India's forests have been a source of 100-200 $MtCO_2\ y^{-1}$ in recent decades (Figure 12).[112] Between 1985 and 1995, estimates range from a weak source of up to about 33 $MtCO_2\ y^{-1}$ to a sink of up to -150 $MtCO_2\ y^{-1}$.[113] From 1995 to 2005, most sources show a moderate to strong sink ranging from near zero to a maximum of -217 $MtCO_2\ y^{-1}$ reported by India's SNC for the year 2000, which is likely a significant overestimation based on a methodological error.[114] From 2005 to 2013 or so, the government time-series estimates generally agree on a slight weakening of the sink,[115] ranging from -50 $MtCO_2\ y^{-1}$ from the FSI carbon stock difference series to -234 $MtCO_2\ y^{-1}$ calculated as the annual difference in the carbon stock estimates for 2005 and 2013 from the NDC.

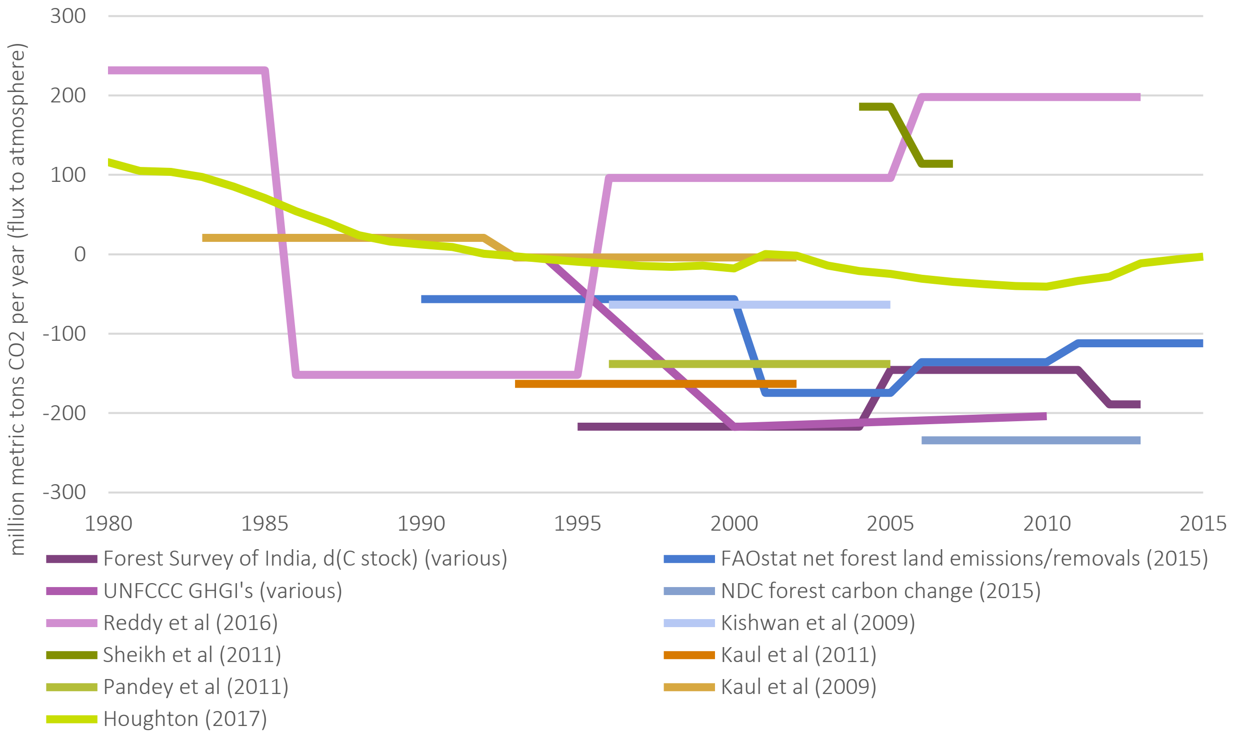
[112] Many of these studies were compiled in Reddy et al (2016) Tables 11 and 12, along with several that are not included here.

[113] Official estimates are in this range: net forest removals reported to FAO (1990-2000) were -56 $MtCO_2\ y^{-1}$, while the 1994 NC1 estimate was -5.55 $MtCO_2\ y^{-1}$.

[114] See Federici et al (2017b). India's calculation in its NC2 and BUR of the sink from lands that transitioned from non-forest to forest assume zero carbon content in all pools (including soil) prior to the transition, which inappropriately inflates the GHGI's net sequestration estimates. Forest land $CO_2$ removals in the NC2 would be -140 $MtCO_2\ y^{-1}$ rather than -217 $MtCO_2\ y^{-1}$ if the change in soil carbon from non-forest to forest were zero. The BUR estimate for 2010 of -204 $MtCO_2\ y^{-1}$ is similarly inflated.

[115] The exception is 2012-2013 fluxes estimated by change in the FSI-reported carbon stock values.

Figure 12. India's forest and land emissions




Notes: Direct government estimates by India are represented by dashed lines. Estimates that combine India's Survey of Forest Resources with either field or remote sensing data for carbon estimation are represented by solid lines. A range of methodologies and carbon pools are included. The UNFCCC GHGI series includes $CO_2$ only, estimated as follows: 1994 is the sum of changes in forest and other woody biomass, forest and grassland conversion, and abandonment of managed lands; for 2000, both forest land remaining forest land and land converted to forest land; and for 2010 the forestland $CO_2$ removal estimate, assumed to be net.

It is unclear how the large drop in forest stock volumes from 2002-2013 reported by FSI (Figure 12) is consistent with the FSI data's apparent increase in forest carbon stock and subsequent net carbon sink. The bookkeeping analysis of FAO-reported forest inventory data by Houghton and Nassikas (2017) shows a temporal pattern that is consistent with other estimates that rely on the FSI: a shift from source to sink in the early 1990s, with a maximum sink around 2010 weakening thereafter.[116] The scale of land sink estimated by Houghton and Nassikas (2017) is much smaller than government estimates, however, hitting a maximum of about 40 $MtCO_2\ y^{-1}$ in 2010, one-fifth the size of India's NDC estimate.

The range of recent forest flux estimates for India place its Paris Agreement goal of an additional carbon sink of 2.5 to 3 $GtCO_2$ into context. Assuming India's intent is for this goal to be achieved over 15 years from 2016-2030, and to include all sequestrations over this period (rather than an increase in sequestrations above and beyond recent rates of sequestration), then a sink of 167-200 $MtCO_2\ y^{-1}$ would be required, a level at or near recent government estimates. Given that India's forests are most likely a weaker sink than government estimates indicated – perhaps significantly so, or even a source rather than a sink as suggested by independent sources, and given that the trend is likely towards decreased removals as suggested by the FAO, Houghton, and government GHGI series, the Paris goal is likely to be quite challenging for India to achieve. It will likely require more extensive forestation effort than has been reported for recent decades.

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[116] Houghton, R.A., and A.A. Nassikas (2017). *Global and regional fluxes of carbon from land use and land cover change 1850–2015*, Global Biogeochemical Cycles 31:456-472, doi:10.1002/2016GB005546. Country-level data were developed in the article cited (but unpublished). Estimate includes all land use and forest emissions.

## Summary and Lessons Learned: India Case Study

While India has long sought to increase its forest cover, large-scale A/R/R efforts began in earnest in the 1980s. Several new programs, an acceleration of budgetary investments in them, and a shift in emphasis towards improving degraded lands and a more inclusive approach to community forestry achieved some apparent success. Government data show large-scale "afforestation" effort averaging 1.5 Mha $y^{-1}$ from 1982-2013, forest cover responding with a slower but still significant average expansion rate of about 200,000 ha $y^{-1}$, and net forest sequestrations in the range of 100-150 MtCO2 y-1 since the mid-1990's. Independent estimates do not fully support government data. The Government has also come to view forestation as a key part of its climate policy and included it as one of only three quantified targets in the country's Paris Agreement NDC. State governments in India will also begin to see large and direct budgetary impacts of their success or failure to protect and expand forests, as USD 6 billion $y^{-1}$ in federal taxes will be distributed to the states based on forest cover.[117]

Several notable lessons from India's experience:

**While many signs point to India's success slowing and possibly reversing forest loss, there are reasons to be cautious in interpreting the scale of India's A/R/R successes and resulting carbon sequestration.** Most troubling is the conflicting information from a few independent studies that show forest cover declining since the 1970s rather than expanding, and/or showing India's forests as a carbon source rather than sink (Sheikh et al 2011, Tian et al 2014, Reddy et al 2016). Second, an apparent inconsistency in India's own forest data between declining forest stock volumes and increasing carbon stocks raises questions. And third, there is a large gap between the scale of "afforestation" identified in government tallies and the actual rate of expansion of forest cover, with as much as 7.5 times as much "afforestation" as forest cover expansion in the last few decades. This gap confirms that much of what is described as "afforestation" is in fact some combination of reforestation, restoration, natural regeneration, and/or planting trees outside forests.

**Unlike South Korea and China, there were no clearly identifiable moments of crisis driving the Indian Government toward large-scale A/R/R.** Rather, a multitude of factors drove policy changes including fuel and fodder provisioning for rural agriculturalists, need for timber supply, watershed management to reduce erosion and support downstream agriculture, broad concerns about environmental degradation and wildlife, and ultimately climate change mitigation. Several enabling conditions also supported India's forestation efforts, including a grassroots environmental movement and cultural ethos supporting harmony with nature, an emphasis on cooperation and shared responsibility between state forestry agencies and local communities, and an early adoption of landscape-scale solutions. The creation of a domestic forest monitoring agency, supported by growing domestic capacity for satellite-monitoring and a large-scale national forest inventory, were also key enabling factors.

**It is also notable that India has provided a reliable and consistent source of finance from Central Planning budgets.** From 1952-1980, about 0.39% of the total Central Planning outlays were allocated to "afforestation;" this increased to over 1% from 1985-1997. Budget support was not always successful in reaching the ground, as with the MGREGNA's difficulty in meeting employment support goals. However, A/R/R has been a consistent priority for the Central Government with concrete programs and budget allocations for implementation since the 1980s, many with an emphasis on devolution of control and implementation to the states and local communities.

[117] See Annex, Table A3 for a summary of India's efforts.

The cost of A/R/R effort in India was substantially lower than in China and South Korea. From 2002-2007, India's forestation programs cost between USD 64 and 161 million per year, only about USD 30-74 per hectare.

Finally, while this case study is cautious in interpreting India's past A/R/R efforts and their success, there are many positive signals that point towards future success. India has set ambitious afforestation goals in the context of strategically important international climate policy. The longer-term targets are supported by research on mitigation potential and cost in the forest sector, in the context of cross-sectoral and inter-ministerial planning. Future targets are also more nuanced – including distinct targets for afforestation, forest restoration/carbon enhancement, and afforestation in small forest-adjacent villages. And finally, a new fiscal devolution formula that allocates about USD 6 billion per year in tax revenues to states based on forest cover (about USD 150 $ha^{-1}$) has the potential to create broader alignment on forest conservation and expansion goals across state government functions.

The study of India's forest and climate reporting in service of an assessment of its A/R/R efforts suggests a few additional lessons related to data and information:

More detailed area and area change data is required for different forest transitions. India's biennial "State of Forest Reports" are a valuable source of detailed information on the country's forest status, and benefit from the integration of both satellite-monitoring and forest inventory approaches. However, it is difficult to interpret the success or failure of India's forestation targets (or even to verify the extent of "afforestation" effort reported in other contexts) without additional detail from the FSI. The FSI's forest cover analysis could be significantly enhanced by providing not only the current forest cover in various categories, but also area transitions between categories. It would be particularly valuable if these reports identified the gross extent of transitions between one survey and the next including: a) area deforested; b) area downgraded from dense to open forests; c) area transitioning from non-forest cover to forest of any type; and d) area transitioning from lower to higher forest densities. At the present time, only net differences can be calculated between one survey and the next.

An explicit assessment of A/R/R effort and outcomes by the FSI would be a valuable addition to the biennial reports. Specific tracking and reporting of the end-state of "afforested" areas, or perhaps of the status of such areas at 5-year intervals after treatment, would increase the ability to understand the scale of effort needed to successfully achieve a particular amount of forest expansion (and thus carbon sequestration) outcome. National policies like the NAP and GIM have distinct targets for different activities that current reporting methods will not be able to assess.

Consistency is required among various official reports. India may consider how best to report across its State of Forests Reports (or other FSI publication), its Five-Year Plans, and UNFCCC submissions its specific plans, targets, actions and achievements to ensure there are no conflicts. For example, it may use more standard definitions of afforestation, reforestation, and carbon enhancement in existing forests, complemented by reporting of efforts to expand trees outside forests. Methodologies and assumptions for converting FSI data into FAO categories should be more transparent.

Reconciling independent and official data may help to improve estimates. Similar to China, discrepancies between FSI-based forest area and forest carbon estimates and independent remote-sensing based estimates are unexplained, as are apparent inconsistencies between forest stock and carbon reporting from FSI reporting. India would be well-served by undertaking an effort to reconcile and explain these differences. Tracking of forest area and status based on both forest cover and land use definitions would allow for more direct comparison with independent data sources and should help reveal dynamics that would likely be obscured by land-use based forest reporting only.

## Conclusions

The story of A/R/R in each case study is unique and interesting in its own right.

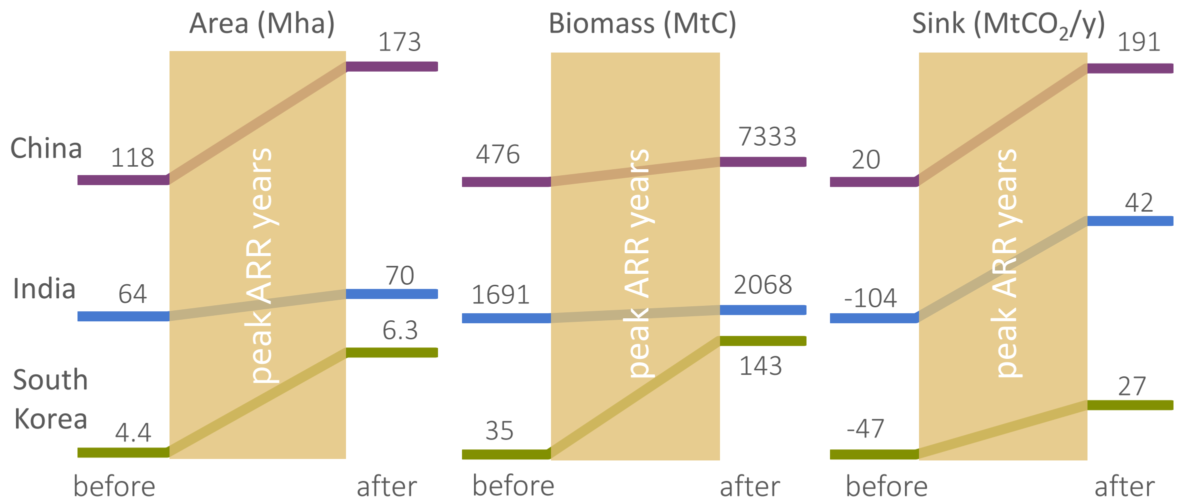
South Korea represents one of the most rapid and striking forest transitions in recent history, starting slowly in the late 1950s, following World War Two and the Korean War, and accelerating in the 1970s and 1980s, when energy poverty, erosion, landslides, and flooding – along with the personal interest of President Park Chung Hee – led to several decades of government-led reforestation policies. South Korea's biggest success has been to dramatically increase tree cover and carbon stocks of degraded forest land rather than to plant new forests on land that was previously used for other purposes. In fact, the total land allocated to forests has declined somewhat, even while national forestry statistics show a dramatic recovery of existing forests that far exceeded the small losses in forest area. Stocked forest area and tree cover increased by about 85% (2.9 Mha total) from 1955 to 1980, while forest wood stock volume increased more than 10-fold from 1970 to 2010—sequestering 966 $MtCO_2$ during this period.

In China, desertification and the southern advance of the Gobi desert toward major agricultural areas began to be perceived as a major threat to food security during the 1970s. In 1978, the government launched the largest forestation project ever envisioned – the "Three Norths Forest Shelterbelt Program" to establish a "great green wall" against the advance of the Gobi, later expanded and complemented by additional programs to reforest upland catchments and reduce runoff, erosion, and degradation of land. The programs set out to increase forest cover from 5% to 15% over 73 years in the arid and semi-arid northern regions of China. Between 1978 and 2012, China planted or seeded between 176-188 Mha of forest through these multiple programs, resulting in an increase of forest area over the period of about 66.5 Mha (over 50%). China's total growing stock volume on both newly planted and existing forests increased by 5.6 billion $m^3$ from 1986 to 2011, resulting in net forest sequestrations of 8.54 $GtCO_2$ from 1994-2012, offsetting 5.8% of China's 2012 emissions from other sectors.

India has sought to restore its forest health and cover since the early 1950s, when it included a long-term objective of increasing forest cover from 23% to 33% of land area in its first National Forest Policy. However, average afforestation rates of about 123,000 ha $y^{-1}$ from 1952-1980 achieved through small-scale "social forestry" programs were no match for the continuing pressure on forests from a largely agrarian and subsistence population, and total forest cover continued to decline. Forestation efforts accelerated in the 1980s with a shift in emphasis towards large-scale afforestation of severely degraded lands, and a focus on community forest management and local involvement in afforestation and forest restoration. Government data show afforestation averaging 1.35 Mha $y^{-1}$ from 1980-2002 leading to a rapidly expanding forest cover from a 1994 nadir through 2004 and continuing to the present, with nearly 47 Mha of total afforestation over the last 33 years. Net forest sequestration of 150 $MtCO_2$ $y^{-1}$ or more has been reported by India to the UNFCCC since the mid-1990s; however, conflicting independent analyses of both forest cover and sequestration suggest caution in interpreting India's official statistics.

**Overall, this study finds strong evidence that through a focus on A/R/R these three countries have arrested forest cover declines and that South Korea and China have expanded forest cover** at scales of millions of hectares within the time frame of only a few decades. There is some evidence that India may have achieved similar scales of forest cover expansion as well. The study also finds strong evidence of significant carbon mitigation in two of the three cases (with China and South Korea achieving net sequestration rates of tens to hundreds of $MtCO_2$ per year), and all three countries report strong and persistent forest sinks as a result of extensive A/R/R (Figure 13).

Figure 13. Strong evidence that A/R/R can increase forest cover and sequestrations




Notes: *China*: peak A/R/R years 1978-2004; forest area from FRIC (various), avg of 1956, 1975 (before) and 2006, 2011 (after) adjusted to estimate 30% cover; biomass from FAO (2014), using earliest available value from 1986 (before) and 2010 value (after). *India*: peak A/R/R years 1986-2009; forest area from FSI (various), avg of 1982, 1986 (before) and 2011, 2013 (after); biomass from FAO (2014), using earliest available value from 1990 (before) and avg of 2010, 2015 (after). *South Korea*: peak A/R/R years 1967-1987; forest area is stocked area from Bae et al (2012), avg of 1955, 1960, 1965 (before) and avg of 1990, 1995 (after); biomass from Choi et al (2002), avg of 1960, 1965 (before) and 1988-1997 (after). *All countries*: sink is 10-year average net forest sink before and after peak years as estimated by Houghton and Nassikas (2017).

The case studies suggest that A/R/R efforts pursued in appropriate ecological contexts can generate large-scale forest cover and forest carbon outcomes. In both India and South Korea, previously degraded forest areas presented the largest opportunity for A/R/R efforts, where ecological conditions could presumably support forests. Restoration was also important in China, but a much larger proportion of effort was directed to establishing trees and forests in areas that had not recently been forested. China's programs to create new forests have seen mixed results, with high rates of failure from early efforts to plant trees where rainfall could not support them; adjustments towards shrubs and drought-tolerant species have helped.

Socio-economic motivating factors for A/R/R action played a key role in each country's experience, and in no case was climate mitigation the primary driving force. In all three countries, the most successful forestation programs – those that generate long term forest cover and forest carbon stock changes – have been closely interwoven with rural economic development. High-profile and acute crises were drivers of political action by central governments in South Korea and China, whereas land degradation provided a "slow burn" driver in India. To varying combinations in all three countries, A/R/R was pursued within a dual frame: a "rural economy" lens, with the goal of providing goods and services to local and forest-dependent communities; and a "crisis" lens, with the goal of reducing harms or risks from forest degradation and deforestation on more distant downstream and downwind populations. This suggests caution in drawing too facile a conclusion that these case studies support large-scale A/R/R for mitigation purposes.

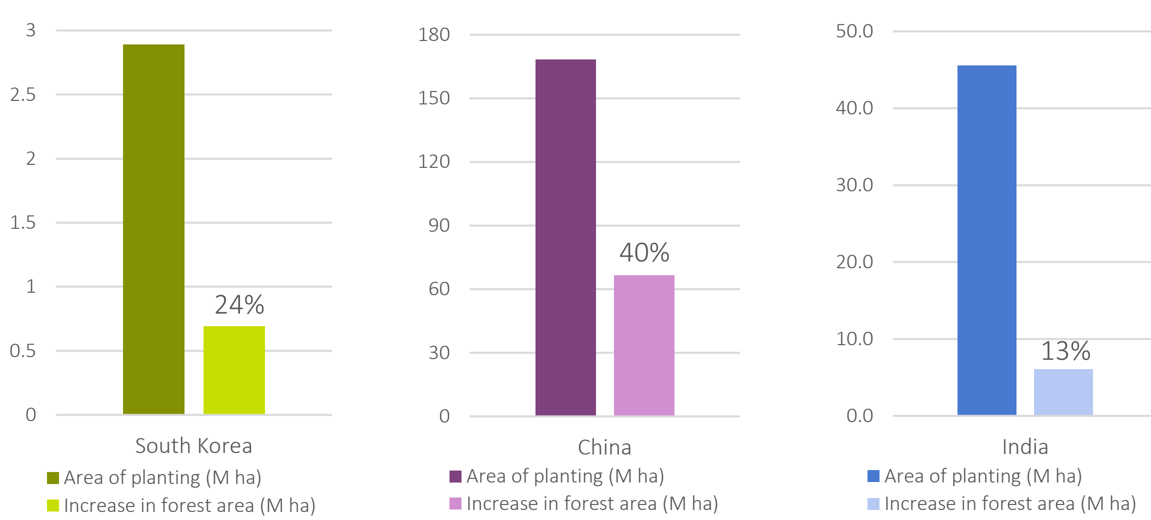
Effective institutional frameworks were critical in all three cases. Especially notable is the role of coordination between forest/environment and economic ministries. For example, in South Korea, the forest service was embedded in the economic ministry for a period of time, and regional and local foresters were formally included in the economic planning and governing processes at those levels. In India, afforestation has been included as a development tool in economic planning cycles, with responsibilities and strategies often shared across rural economic development and environment/forest ministries. This type of multilevel and interministerial coordination may be more challenging in the context of climate-based A/R/R programs, as central responsibility for climate mitigation may be housed elsewhere, and climate leaders may be more focused on coordination with energy-related ministries than with forest and agricultural agencies.

**Implementation approaches, capacity and resources—including cost—also played a role**. Community buy-in and participation have been particularly important in South Korea and India's programs, while in China the use of enforcement and economic inducement were more prominent. Estimates of the cost of A/R/R action vary widely across and within these case studies. Budgetary costs in India ranged from USD 30-74 per hectare from 2002-2007 to more recent allocations of about USD 720 per hectare. The cost of South Korea's rehabilitation efforts over the period of greatest planting were USD 1443-1603 per hectare from 1973-1987. China's 2000-2009 expenditures for its six key forestry programs was still higher, at USD 2151-2317 per hectare. Rough estimates of cost per ton of sequestration range from a low of USD 1.00 per ton $CO_2$ in India, to USD 12.90 per ton in South Korea, to USD 25.60 per ton in China. In all three cases it is clear that governments needed to invest a huge amount of money – in absolute terms – into these programs. South Korea was investing more than 1% of its total national budget during its most intense period of A/R/R, about USD 197 million per year. China invested about USD 11 billion per year from 2000-2009 on forestation, and India reached the same USD 10 billion per year by 2014.

This research also identified several lessons learned across the case studies relating to goal-setting, reporting and information that are important in considering how to interpret existing global A/R/R goals and how to best support the success of A/R/R for climate mitigation purposes.

First, **there is a consistent and large difference between reported afforestation and reforestation areas and observed changes in forest cover** – ranging from a 2.5:1 ratio in China to as high as 7.5:1 ratio in India (Figure 14). This gap could be the result of several issues, including unsuccessful afforestation; restoration misidentified as "afforestation," taking place in areas already identified as forest; reseeding or planting of recent harvests incorrectly reported as afforestation; afforestation that is compensating for unidentified deforestation in other places; a delay between tree planting and satellite observation meeting forest height and canopy closure thresholds; inconsistent definitions; and inaccurate reporting.

**Figure 14. Area of A/R/R interventions do not translate directly into increased forest area**



## Are the lessons from South Korea, China and India replicable?

There are some important caveats in extending the lessons from these case studies to other countries that may pursue A/R/R for climate mitigation:

- In the most unambiguously successful two out of the three cases, large-scale action was precipitated by crises, or risks perceived by central governments as unacceptably high. It is not clear whether climate change is yet perceived by the people and leadership of most countries as a crisis or unacceptably high risk. Countries where severe forest degradation leads directly to flooding, drought, dust, or other crises may be more likely to pursue forestation even in the context of climate commitments. A country whose political leadership perceives climate change to present unacceptably high risks may also be more likely to succeed in setting and prioritizing A/R/R actions.
- In all three cases, A/R/R efforts were framed as providing direct economic benefits to forest-dependent and forest-adjacent communities (even if they were not always successful at contributing to rural economic growth). This will no doubt be necessary for future mitigation-based forestation to be successful in other countries as well.
- There are serious tradeoffs between production- or plantation-based A/R/R and protective or natural forest A/R/R. The economics work out more easily and quickly for plantations. Non-climate ecosystem benefits, such as biodiversity and water services, are greater for protective or natural A/R/R. Climate benefits are mixed: a protected natural forest will have sequestered more carbon from atmosphere to land when mature than a productive forest rotation, although production forests achieve greater removals in the near term.[118] Much of the forestation observed in these case studies was plantation forestry of some sort. Commercial forestry plantings and other economic tree crops have to date provided greater direct economic benefits than restoration of biologically diverse forest. Natural forest A/R/R mitigation will likely require greater subsidies or enforcement to succeed.
- Efforts at replanting existing degraded or recently cleared forests (restoration and reforestation) appear to have been more common and successful than efforts to expand forest cover in new areas (afforestation). This suggests focusing efforts both within and between countries on degraded forests. It also suggests careful consideration of how to sum across the mitigation potentials from afforestation/reforestation and from avoided deforestation and forest degradation. The two are not simply additive.
- Accounting for the direct impact of A/R/R efforts on forest area and carbon sequestration is difficult. Much more extensive activity and outcome data will be necessary if attribution is required in the context of climate mitigation commitments.
- Large-scale forestation is a decadal-scale proposition. It takes decades to cover large areas with trees and/or to restore large areas of forests to health; decades to reach maximum mitigation sequestration, resulting from the combined time needed for large-scale implementation plus a decade or more for new plantings to reach maximum removal rates, depending on forest type and management; and carbon removal will continue for decades thereafter, although more and more slowly as forests age. Tree planting may not deliver a huge amount of mitigation immediately, but it is a solution that can ramp up for decades, reach globally significant levels, and deliver benefits for a very long time (although not forever).

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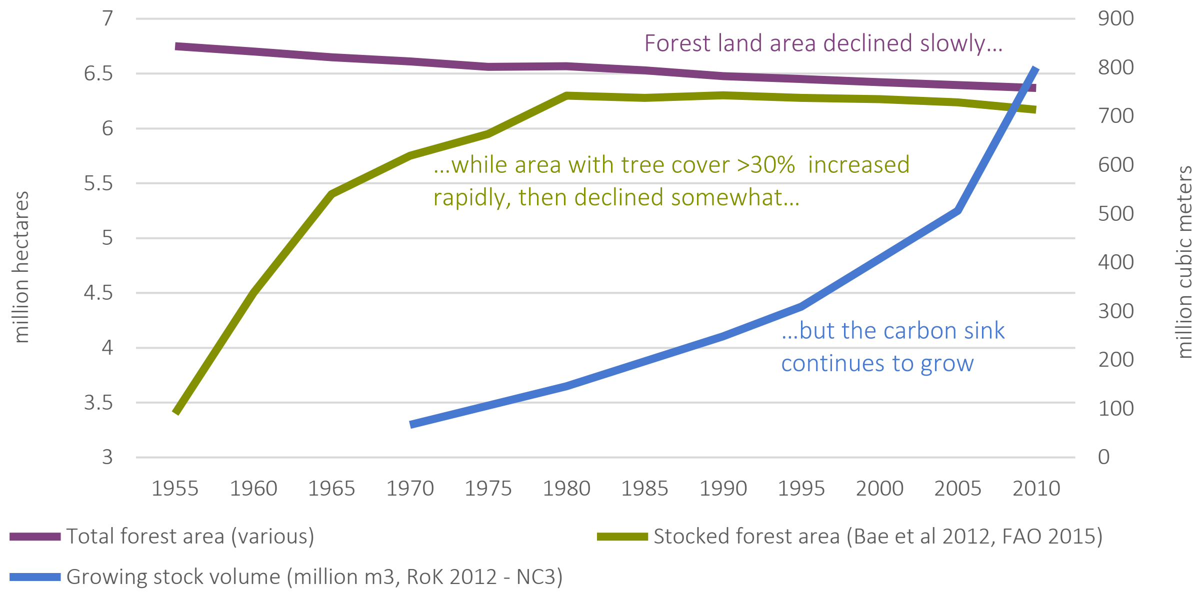
[118] A productive forest rotation could theoretically achieve greater overall mitigation through time if coupled with a high proportion of long-lived harvested wood products and/or with BECCS, but neither approach is proven.

Second, it is clear **that forest area trends alone provide a poor measure of A/R/R success and mitigation.** Changes in forest area – especially if defined by land use rather than tree cover – may be very poorly correlated with carbon sequestration. Alternative measures such as forest volume, stocking rate, and carbon density that more directly speak to the density of trees in forests are better indicators that A/R/R actions have achieved carbon impacts. For example, forest area in South Korea has been declining while carbon sinks continue to grow (Figure 15).

Figure 15. Forest area is not always the best indicator of A/R/R success for climate mitigation




Third, the case studies reviewed here prioritize active interventions centered on tree planting and maintenance. It is important to note that in the broader context, some forestation programs rely more on passive interventions to allow natural regeneration of forests. Data on such "non-ARR" forestation approaches has not yet become a staple of governmental reporting but may have substantial potential.

Fourth**, consistent and effective monitoring is critical for both adaptive management and assessment of A/R/R efforts and outcomes**. The information provided by China's and India's extensive National Forest Inventories to policymakers, South Korea's careful external monitoring of restoration areas, and China's clarity and precision in reporting to the FAO all provide examples of the type of data and information critical to understanding the success of A/R/R efforts.

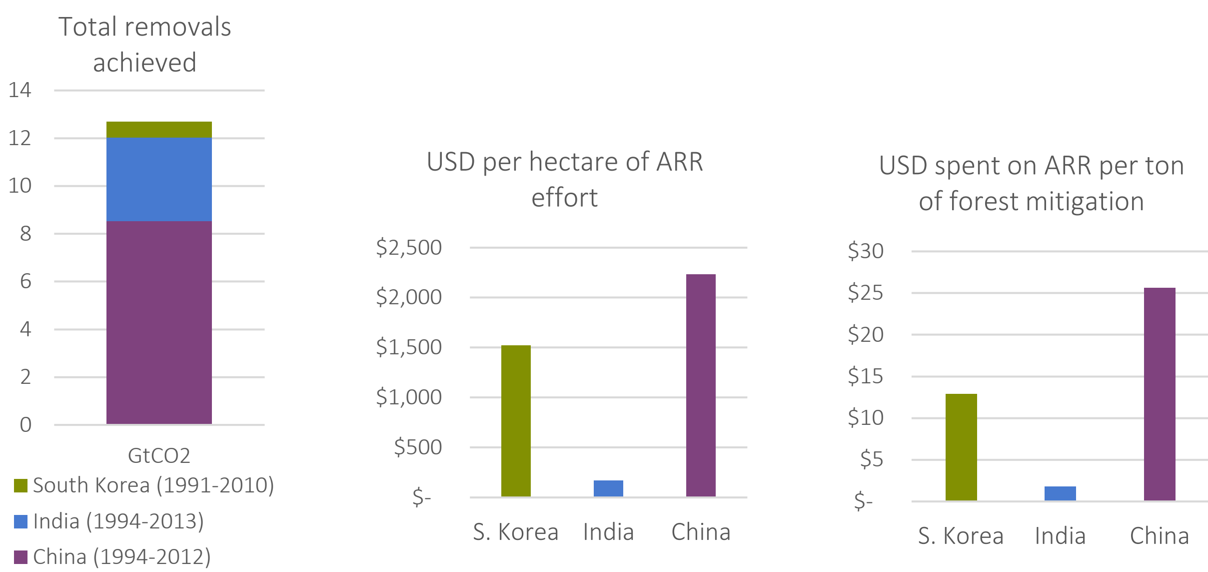
Taken together, these lessons suggest that **A/R/R goals in a climate context should be outcome-based rather than input-based, and linked directly to the forest carbon statistics that a country tracks in its national forest inventories**. Climate policy makers should view with caution targets stated in terms of total forest area or forest area change, or input-based A/R/R mitigation action targets such as "achieve X hectares of afforestation."

**Overall, this study suggests that large-scale A/R/R should be taken seriously as a major focus for additional climate mitigation action around the world.** Globally, forests have been a large and persistent sink of nearly 15 $GtCO_2$ $y^{-1}$.[119] Forests thus offset GHG emissions from other sectors and buffer the world from climate change impacts. This paper demonstrates that three countries have achieved very

[119] Pan et al 2011 for the period 1990-2007.

significant forest turnarounds and tree planting, yielding $CO_2$ sequestrations in the tens to hundreds of megatons per year and total removals of over 12 GtCO2 over the past two decades or so (Figure 16). Such large-scale sequestration may be replicated, under the right conditions, contributing to Paris Agreement goals.

Figure 16. Significant mitigation has been achieved over the last two decades at reasonable cost



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# Annexes

## Annex 1: India's Primary Afforestation Programs and Objectives[120]

| Program/law | Goals and/or targets | Responsible Agency |
|---|---|---|
| **Integrated Afforestation and Eco-Development Program (1989)** | Restore and regenerate the ecological balance of degraded forests using a participatory approach.[121] | Ministry of Environment and Forests (MoEF); State Forest Departments; National Afforestation and Eco-Development Board (NAEB) |
| **Integrated Wasteland Development Program (1989-1990) (IWDP)** | Regenerate degraded non-forest land through silvipasture and soil and water conservation on the village and micro-watershed scale.[122] | Ministry of Rural Development (MoRD) |
| **Joint Forest Management/Social Forestry (2000) (JFM)** | Implementation approach to the 1988 National Forest Policy; "a forest management strategy under which the government (Forest Department) and the village community enter into an agreement to jointly protect and manage forestlands adjoining villages and to share responsibilities and benefits." Focused originally on degraded forests but was expanded to include healthy forests. [123] | MoEF |
| **National Afforestation Programme (2002) (NAP)** | Afforestation and reforestation of both degraded forests and non-forest areas.<br>Targets:<br>3 Mha afforestation/reforestation 2002-2007<br>~20 Mha land rehabilitation[124] | MoEF, NAEDB |
| **Compensatory Afforestation Fund Management and Planning Authority (2004, 2016 update) (CAMPA)** | Management and use of funds generategy by a levy on deforestation, intended to support equal areas of afforestation. Largely a state-level program. A 2016 update was passed to more quickly distribute USD 6 billion in accumulated levies. | CAMPA |

[120] These programs were cited as relevant to afforestation efforts in India's BUR (2015) and/or its NDC (2016), or in accounts of India's related programs in the literature including Damodaran and Engel (2003), Ravindranath et al (2008), Gray and Srinidhi (2013), and Reddy et al (2016). Not included are the underlying or related legal instruments, most notable the Wildlife (Protection) Act of 1972, the Forest Conservation Act of 1980, and the National Forest Policy initially passed in 1952 and heavily revised in 1988.
[121] Gray and Srinidhi (2013)
[122] Gray and Srinidhi (2013)
[123] Damodaran and Engel (2003), including their quote from a 2002 MoEF circular on JFM and social forestry.
[124] BUR (2015)

| Program/law | Goals and/or targets | Responsible Agency |
|---|---|---|
| **Mahatma Gandhi National Rural Employment Guarantee Scheme (2005) (MGNREGA)** | A rural employment scheme intended to guarantee a minimum of 100 days of employment for the rural poor in a variety of jobs that serve public purposes, including subsidized tree planting for drought-proofing. | MoRD |
| **Green India Mission (2008) (GIM)[a]** | The forestry component of the National Action Plan on Climate Change, aiming to enhance carbon stocks and improve forest quality and tree cover using participatory approaches.<br>Targets:<br>5 Mha afforestation/reforestation from 2010-2020<br>5 Mha improved forest/tree cover from 2010-2020 | Implemented through existing programs and agencies |
| **Integrated Watershed Management Programme (2009) (IWMP)** | Consolidated existing programs including IWDP, the Drought Prone Area Program and the Desert Development Program. | MoRD |
| **Low Carbon Strategy (2014)[125]** | The Expert Group recommended a set of actions and targets for enhancing carbon sinks through 2030.<br>Targets:[b]<br>Conserve existing 16 Mha of protected areas<br>Sustainable management of 53 Mha of other forests<br>2 Mha $y^{-1}$ forest cover improvements, 1 Mha $y^{-1}$ each from open to medium dense forests, and from medium dense to very dense forests<br>1.7 Mha $y^{-1}$ afforestation (both forest and tree cover) in and around forest fringe villages | Planning Commission |
| **Central to State Tax Devolution Allocation Formula (2015)** | Devolution to states of about USD 6 billion per year in national tax revenues on the basis of forest cover as measured by the FSI, for climate and ecological benefits. | Finance Commission |
| **National REDD+ strategy (pending)** | Pilot projects ongoing, with a National REDD+ strategy drafted and in review | MoEFCC |

Notes: a. Also known as the National Mission for a Green India. b. Only targets listed in the BUR are included; the Expert Group also recommended improved cookstoves, an afforestation goal under GIM of 6 Mha total, and increased use of wood in longer-lived products.

[125] Strategy was developed by the Expert Group on Low Carbon Strategies for Inclusive Growth, organized by the Planning Commission.

## Annex 2: Notable Data Discrepancies

| Country | Measure | Sources | Scale | Trend |
|---|---|---|---|---|
| South Korea | Forest area | RoK, Hansen | *Similar*. Total forest area reported by RoK for 2000 is ~20% higher than Hansen[1] | *Same*. |
| | Stocked forest area | FAO, Hansen | *Similar*. Stocked forest area reported by RoK to FAO for 2000 is ~17% higher than Hansen[2] | *Same*. |
| | Forest land $CO_2$ removals | NC3 (2012), BUR (2014), Houghton (2017)[3] | *Different*. BUR estimates a 50-80% larger sink than earlier NC3 (32-62 Mt $y^{-1}$ versus 22-43 Mt $y^{-1}$)[4]; BUR and Houghton are similar in early 1990s, but BUR estimates are 2-3 times higher than Houghton from late 1990s through present (~60 Mt $y^{-1}$ versus ~20 Mt $y^{-1}$) | *Similar*. Houghton estimates peak sequestration in 1991 with decline thereafter; the BUR shows sequestration increases through 1999 and much later declines. The BUR shows more stable estimates for 2000s than NC3 and decreasing removals starting in 2008. |
| China | Forest area | FRIC[5], Liu et al (2005), Hansen et al (2013), Viña et al (2016) | *Similar*. Differences of 0-20% in total forest area estimates, depending on the year | *Some significant differences*. Liu et al (2005) shows stable or slightly decreasing forest area from 1990-2000, while FRIC shows an increase of 18% (26 Mha) from 1991-2001. Hansen et al (2013) suggests much higher forest area loss than gain from 2001-2012, while FRIC shows increases. Viña et al (2016) find 16 Mha with increased forest cover and 4 Mha with decreases from 2000-2010, compared to FRIC's 22 Mha net forest gain at 20% cover threshold |
| | Forest $CO_2$ removals | GHGIs, FAOStat, independent studies | *Some differences.* GHGI and FAO estimates are at the high end or higher than most published estimates.[6] Houghton (2017)'s forest sink estimates are 45, 62, and 38% of the UNFCCC-reported LUCF sink for 1994, 2005, and 2012 respectively. | *Some differences*. Few studies show a clear trend, although across studies there appears to be an increase in China's sink from the 1980s to the 2000s at least. China's GHGIs show a 37% increase in its forest sink from 2005-2012, while Houghton shows the sink decreasing by 15% over that period, peaking at 263 MtCO2 y-1 in 2007 and declining thereafter. |
| India | Forest area | FSI,[7] FAO, Tian et al (2014), Reddy et al (2016), Hansen et al (2013) | *Some differences.* FSI and FAO estimates of 63-70 Mha are very close to independent estimates by Tian et al (2014) and Reddy et al (2016) from the 1980s to 1990s, diverging by up to 12% by 2013. Hansen et al (2013) find year 2000 forest area to be 75% of the FSI estimate.[8] | *Different*. FSI and FAO show an increase in forest area from through 2013, while Reddy et al (2016), Tian et al (2014), and Hansen et al (2013) all show declines in forest area over comparable time periods. |

| Country | Measure | Sources | Scale | Trend |
|---|---|---|---|---|
| | Growing stock volume | FSI, FAO | *Some differences.* Growing stock estimates range from 4000-5500 $Mm^3$ depending on year and source[9] | *Different*. FSI data show decreasing volumes from 2002-2013, while FAO data suggest increasing volume from 1990 to at least 2005 or 2010. |
| | Forest $CO_2$ removals | GHGIs, FAOStat, independent studies | *Different*. From 1985-1995, estimates range from a weak source (~33 $MtCO_2\ y^{-1}$) to a strong sink (-150 $MtCO_2\ y^{-1}$). From 1995-2005, government-based sources show a moderate to strong sink (up to -217 $MtCO_2\ y^{-1}$). Two independent studies (Reddy et al 2016, Sheikh et al 2011) show a large source of 100-200 $MtCO_2\ y^{-1}$ after 1995. Houghton's forest sink estimates are similar for 1994 but much smaller than the UNFCCC-reported LUCF sink for 2000 (-18 vs -217 MtCO2 y-1) and 2010 (-41 vs -204 MtCO2 y-1). | *Some differences*. Overall, data suggest an increase in removals from the mid 1980s through the 2000s, and a weakening sink thereafter, but some series show conflicting temporal trends. Houghton shows a sink beginning in 1993 and generally increasing through 2010 then weakening; government GHGI's show a similarly growing then weakening sink with some difference in timing. |

[1] Comparison uses 30% threshold for Hansen, the same as used by RoK for its reporting.
[2] Comparison uses 30% threshold for Hansen, the same as used by RoK for its reporting to FAO.
[3] Houghton, R.A., and A.A. Nassikas (2017). *Global and regional fluxes of carbon from land use and land cover change 1850–2015*, Global Biogeochemical Cycles 31:456-472, doi:10.1002/2016GB005546. Country-level data were developed in the article cited (but unpublished).
[4] There was no clear explanation for the change in South Korea's BUR.
[5] Forest Resources Inventory of China, various years. Comparisons are at 20% cover threshold.
[6] The exception is Pan et al 2011. Most published estimates rely on FRIC for area and area changes, but apply alternative methods for calculating carbon fluxes. The 5th FRIC released in 2000 adjusted upward earlier-period forest area expansion estimates, which may explain some of the differences. See text.
[7] Forest Survey of India, data reported in regulary Stateof Forests Reports.
[8] Comparing Hansen tree cover at 10% threshold to FSI data including open, dense, and very dense forests – all forests over 10% cover.
[9] Excluding trees outside forest.

# Annex 3: Country Summary Tables

## South Korea

| Measure | Pattern | Quantitative Estimates | | | | | |
|---|---|---|---|---|---|---|---|
| **Forest Area** | | | | | | | |
| | | Absolute | | Absolute Change | | Rate of Change | |
| Land registration or land use definition[1] | Small and slow decline from ~1930 to present | ~1930 | ~6.9 Mha (69% land) | ~1930-2010 | Loss of ~460 Kha over 80 years | ~1930-2010 | Loss of ~5,700 ha $y^{-1}$ (0.09% $y^{-1}$) |
| | | 1950's | ~6.8 Mha (68%) | | | | |
| | | 2010 | 6.37 Mha (64%) | | | | |
| Tree cover or "stocked forest area"[2] | Large decline from ~1940 peak through 1950s, rapid recovery to 1980s, slight decline to present | ~1940 | ~5 Mha (73% of forest) | ~1940-1955 | ~1.6 Mha destocked and/or converted | ~1940-1955 | ~110 Kha $y^{-1}$ destocked or converted |
| | | ~1955 | ~3.4 Mha (50%) | 1955-1980 | ~2.9 Mha restocked | 1955-1980 | 116 Kha $y^{-1}$ restocked |
| | | 1980 | ~6.3 Mha (96%) | 1980-2010 | ~170 Kha destocked and/or converted | 1980-2010 | 5 Kha $y^{-1}$ destocked or converted |
| | | 2010 | ~6.16 Mha (97%) | | | | |
| **Area Impacted** | | | | | | | |
| | | Absolute | | | | Rate of Change | |
| Replanted, restored, reforested, and/or afforested[3] | Large-scale government reforestation & forest restoration efforts from 1967 to 1987 | 1967-1972 | ~784 (~435) Kha planted (survived)[4] | | | 1967-1972 | 131 (73) Kha $y^{-1}$ |
| | | 1973-1979 | 1.19 (1.07) Mha | | | 1973-1979 | 198 (178) Kha $y^{-1}$ |
| | | 1980-1987 | 860 (776) Kha | | | 1980-1987 | 108 (97) Kha $y^{-1}$ |
| | | 1988-2010 | 611 Kha | | | 1988-2010 | 27 Kha $y^{-1}$ |
| | | 1967-2010 | 2.9 Mha | | | 1967-2010 avg | 66 Kha $y^{-1}$ |
| **Forest Stocks, Carbon and Emissions** | | | | | | | |
| | | Absolute | | Absolute Change | | Rate of Change | |
| Forest wood stock volume[5] | Accumulating volume from 1970s with increasing rate | 1970 | 67 million $m^3$ | 1970-2010 | 733 $Mm^3$ over 40 yrs | 1970-2010 | 18.3 $Mm^3$ $y^{-1}$ |
| | | 1980 | 146 $Mm^3$ | | | 1970-1980 | 7.9 $Mm^3$ $y^{-1}$ |
| | | 1990 | 248 $Mm^3$ | | | 1980-1990 | 10.3 $Mm^3$ $y^{-1}$ |
| | | 2000 | 408-526 $Mm^3$ | | | 1990-2000 | 15.9 $Mm^3$ $y^{-1}$ |
| | | 2010 | 799-800 $Mm^3$ | | | 2000-2010 | 27.3-39.3 $Mm^3$ $y^{-1}$ |
| Forest biomass and net forest sequestrations | Same | 1970 | 35 MtC[6] | 1970-2000 | 172 MtC/629 $MtCO_2$ | 1970-1980 | 13 (12) $MtCO_2$ $y^{-1}$ |
| | | 1980 | 71.5 MtC | | (177 MtC/650 $MtCO_2$)[7] | 1980-1990 | 20 (26) $MtCO_2$ $y^{-1}$ |
| | | 1990 | 126.5 MtC | | | 1990-2000 | 23-42[8] (27) $MtCO_2$ $y^{-1}$ |
| | | 2000 | 206.5 MtC | | | 2000-2010 | 37-61 (24) $MtCO_2$ $y^{-1}$ |
| **Cost** | | | | | | | |
| | | Absolute | | Per ha, year and $tCO_2$ | | | |
| Planting, restoration, reforestation, and afforestation | NA | 1973-1987 | 592 billion Won[9] | 1973-1987 | \$1443-1603[11] $ha^{-1}$ | | |
| | | | \$3 billion[10] | | \$197 million $y^{-1}$ | | |
| | | | | 1973-1987 spending vs 1973-1987 sequestration: \$12.9[12] per $tCO_2$ | | | |

[1] Bae et al (2012) through 1990, compiled from Japanese and South Korean government statistics; FAO (2015) for 1990-2010.
[2] Bae et al (2012) through 1990; FAO (2015) for 1990-2015.
[3] Lee (2013) for 1967-1987, FAO (2015) from 1988-2010
[4] Estimates for 1967-1987 include both planted area and planted areas that survived, following Lee (2013). After 1988, only a single estimate of reforestation is available for each year from FAO (2015). Averages across both periods include survived area from Lee (2013).
[5] Estimates of growing stock volume are from South Korea's Third National Communication to the UNFCCC (TNC) through 1990; the range in 2000 is from the TNC (low) and FAO (2015) (high), while the 2010 value is nearly identical from the TNC and FAO (2015).
[6] Forest biomass carbon stock from Choi et al (2002).
[7] Estimates in parenthases are from Houghton, R.A., and A.A. Nassikas (2017). *Global and regional fluxes of carbon from land use and land cover change 1850–2015*, Global Biogeochemical Cycles 31:456-472, doi:10.1002/2016GB005546. Country-level data were developed in the article cited (but unpublished).
[8] Ranges include period averages for all estimates in Figure 4, including forest biomass increment (Choi et al 2002), forest land removals (RoK 2014 – BUR, and RoK 2012 NC3), carbon uptake rate (Lee et al 2002), and net ecosystem production (Cui et al 2014).
[9] Youn et al 2006.
[10] Nominal USD estimated as $1 billion, based on annual average USD-KRW exchange rate for each year from 1973-1987 and an assumed average annual expenditure of 39.5 billion KRW. 2016 real USD estimated from nominal USD using GDP deflators.
[11] Range is USD2016 per hectare planted (low) or successful (high) as estimated by Lee (2013).
[12] Estimate is USD2016 per ton $CO_2$ sequestered as estimated by changes in forest biomass from Choi et al (2002).

## China

| Measure | Pattern | Quantitative Estimates | | | | | |
|---|---|---|---|---|---|---|---|
| **Forest Area** | | | | | | | |
| | | Absolute | | Absolute Change | | Rate of Change | |
| Total forest area | Long and gradual decline with nadir sometime between 1950-1981, then increasing to present | ~1700 | 176-322 Mha[1] (19-34% land area) | ~1700-nadir | Loss of 91-201 Mha over 250-280 yrs[5] | ~1700-nadir | Loss of 360-390 Kha $y^{-1}$ (0.29–0.34% $y^{-1}$) |
| | | 1950-1981 | 85-121 Mha[2] (9-13% land area) | nadir to 1991 | Gain of 18-53 Mha over 12-40 years[6] | nadir to 1991 | Gain of 1.29-1.54 Mha $y^{-1}$ (1.18-1.24% $y^{-1}$) |
| | | 1991 | 134-158 Mha[3] (14-17% land area) | 1991-2011 | Gain of 43-48 Mha over 20 years[7] | 1991-2011 | Gain of 2.17-2.41 Mha $y^{-1}$ (1.22-1.44% $y^{-1}$) |
| | | 2011 | 193-202 Mha[4] (20.6-21.5% land area) | 1979-2011 | Gain of ~66.5 Mha over 32 years[8] | 1979-2011 | Gain of 2.08 Mha $y^{-1}$ (1.33% $y^{-1}$) |
| Plantation area[9] | Steady increase from mid-1980s to present[10] | 1986 | 27.7 Mha (22% of forest) | 1986-2011 | 36.5 Mha new plantations | 1986-2011 | 1.46 Mha new plantations $y^{-1}$ |
| | | 2011 | 64.2 Mha (33% of forest) | | | | |
| **Area Impacted** | | | | | | | |
| | | Absolute | | | | Rate of Change | |
| Afforestation by planting/seeding or air seeding, or other means | Large-scale government effort to expand forests since 1979 or earlier | 1978-2012 | target ~68-77 Mha[11] ~176-188 Mha planted[12,13] | | | 1978-2012 | 5.2-5.5 Mha $y^{-1}$ |
| | | 2001-2010 | target ~50.4-55.6 Mha[14] ~49-57 Mha planted | | | 2001-2010 | 4.9-5.7 Mha $y^{-1}$ |
| **Forest Stocks, Carbon and Emissions** | | | | | | | |
| | | Absolute | | Absolute Change | | Rate of Change | |
| Forest growing stock volume[15] | Accumulating volume from 1979 | 1986 | 9.69 billion $m^3$ 76 $m^3$/ha average | 1986-2011 | Gain of 5.56 B $m^3$ over 25 years | 1986-2011 | 222 M $m^3$ $y^{-1}$ |
| | | 2011 | 15.24 B $m^3$ 89 $m^3$/ha average | | | | |
| Net forest sequestrations | Large and increasing in the last decade | 1994 | 20.2 $GtCO_2$ stock[16] | 1994-2005 | 4.97 $GtCO_2$ sink[17] (2.58 $GtCO_2$)[18] | 1994 | 408 $MtCO_2$ $y^{-1}$ (182 $MtCO_2$ $y^{-1}$) |
| | | 2005 | 24.6 $GtCO_2$ stock | 2006-2012 | 3.57 $GtCO_2$ sink (1.88 $GtCO_2$) | 2005 | 421 $MtCO_2$ $y^{-1}$ (281 $MtCO_2$ $y^{-1}$) |
| | | 2012 | 27.6 $GtCO_2$ stock | 1994-2012 | 8.54 $GtCO_2$ sink | 2012 | 576 $MtCO_2$ $y^{-1}$ (247 $MtCO_2$ $y^{-1}$) |
| **Cost** | | | | | | | |
| | | Absolute | | Per ha, year and $tCO_2$ | | | |
| Total cost, Six Key Forestry Programs | NA | 2000-2009 | RMB 725 billion USD2014 113 billion[19] | 2000-2009 | USD 2151-2317 $ha^{-1}$ USD 11.3 billion $y^{-1}$ | | |
| | | | | 2000-2009 spending vs 2000-2009 sequestration:[20] | USD 25.6 $tCO_2^{-1}$ | | |

[1] Range of historical reconstructions. Minimum is Liu and Tan (2010); maximum is Houghton and Hackler (2003); Ramankutty and Foley (1999) and He et al (2007) fall within.
[2] Range of nadir values from historical reconstructions and Forest Resources Inventory of China series. Minimum is Liu and Tan (2010) estimate for 1950; maximum is Houghton and Hackler (2003) estimate for 1980. FRIC nadir is 115 Mha (12%) from NFI2 (1977-1981).
[3] Range is from FRIC estimate for NFI4 (1989-1993) at 30% cover (low), to FAO estimate at 10% cover and land use definition (high). FRIC estimate at 20% cover is 145 Mha.
[4] Range is from FRIC estimate for NFI8 (2009-2013) at 20% cover (low), to FAO estimate at 10% cover and land use definition (high).
[5] Range is from Liu and Tan (2010) from ~1700-1950, to Houghton and Hackler from ~1700-1980 (high).
[6] Range is from FRIC 30% series from 1979 to 1981 (low), to Liu and Tan (2010) from 1950 to 1991 (high).
[7] Range is from FAO (low) to FRIC 20% (high).
[8] Estimated from FRIC series adjusted to account for 30% to 20% cover threshold change. Corresponds to Figure 6, purple series.
[9] All data in row from PRC reports to FAO FRA.
[10] Plantation area prior to this is not reported to FAO FRA.
[11] Range is calculated from Table 1, including 25-31.5 Mha for TNSFP, 32 Mha for GGP, 10.6 Mha for Forest Industrial Base Development Program, and up to 5.2 Mha from Sand Control Program.
[12] Reported by PRC to FAO FRA for most years; annualized estimates of “new planted areas” from Zhang and Song (2006) used for 1978-1987 and to estimate missing FAO data for 1993-1997. Corresponds to Figure 6, green series.
[13] In its report to FAO FRA2015, China included new area estimates of forest restoration from “Enclosing hillsides: non-standing trees land, open land,” “Enclosing hillsides: shrub land,” and “Afforestation under trees canopy.” It is not clear if these types of forest restoration were previously reported as “Afforestation by planting/seeding or air seeding” or simply excluded. From 2007 to 2012, 62% of 37.8 Mha of reported reforestation efforts were planting/seeding, 6% slash regeneration, 26% enclosing hillsides on open land, 5% enclosures on shrub land, and 2% afforestation under tree canopy. These categories (excluding slash regeneration) would add 12.3 Mha of restoration from 2007-2012, or 8 Mha from 2007-2010 – included in the higher end estimates in this row.
[14] Range is calculated from Table 1, including 9.5 Mha for the TNSFP, 32 Mha from the GGP, 8.9 Mha of the Forest Industrial Base Development Program, and up to 5.2 Mha from the Sand Control Program.
[15] All data in row from PRC reports to FAO FRA for both arbor forests (>20% cover) and open forests (between 10% and 20% cover). Excludes bamboo forests, economic forests, and scattered/four-side trees.
[16] Stocks calculated for arbor and open forests, including AGB, BGB, and Deadwood, based on FRA reporting.
[17] Estimates of total and annual $CO_2$ sequestrations based on China’s reported LUCF emissions in UNFCCC greenhouse gas inventories. Linear interpolations between 1994, 2005, and 2012 values used to calculate total sink over the period.
[18] Estimates in parenthases are from Houghton, R.A., and A.A. Nassikas (2017). *Global and regional fluxes of carbon from land use and land cover change 1850–2015*, Global Biogeochemical Cycles 31:456-472, doi:10.1002/2016GB005546. Country-level data were developed in the article cited (but unpublished).
[19] Nominal USD 100 billion estimated based on annual expenditures and annual exchange rates. Equivalent to about USD2016 113 million, converted to real USD based on GDP deflators.
[20] USD2016 113 billion divided by an estimated 4411 $MtCO_2$ total sequestration from 2000-2009, based on interpolation of UNFCCC reported values of 408, 421 and 576 $MtCO_2\ yr^{-1}$ in 1994, 2005, and 2012 respectively.

## India

| Measure | Pattern | Quantitative Estimates | | | | | |
|---|---|---|---|---|---|---|---|
| **Forest Area** | | | | | | | |
| | | Absolute | | Absolute Change | | Rate of Change | |
| Total forest area | Long, gradual decline with likely stabilization during the 1980s; government data showing rapid increase 1994 to 2004 and slower increase to present | ~1700 | ~118 Mha[1] (36% land area) | ~1700-1994 | Loss of ~54 Mha over 294 yrs | ~1700-1994 | Loss of ~184 Kha $y^{-1}$ (0.21% $y^{-1}$) |
| | | 1994 | 63.3 Mha[2] (19.3%) | 1994-2004 | Gain of 5.4 Mha | 1994-2004 | Gain of 540 Kha $y^{-1}$ (0.82% $y^{-1}$) |
| | | 2004 | 68.7 Mha (20.9%) | 2004-2013 | Gain of 1.5 Mha | | |
| | | 2013 | 70.2 Mha (21.3%) | | | 2004-2013 | Gain of 160 Kha $y^{-1}$ (0.23% $y^{-1}$) |

| Measure | Pattern | Quantitative Estimates | | | |
|---|---|---|---|---|---|
| **Area Impacted** | | | | | |
| | | Absolute | | Rate of Change | |
| Afforestation area[3] | Large-scale government effort to expand forests since at least 1980 | 1952-1980 | ~3.6 Mha[4] affor | 1952-1980 | ~123 Kha $y^{-1}$ |
| | | 1980-2002 | ~29.6 Mha[5] affor | 1980-2002 | ~1.35 Mha $y^{-1}$ affor |
| | | 2002-2007 | target: 3 Mha affor plus ~20 Mha restor[6]<br>actual: 10.9 Mha[7] affor | 2002-2007 | target: 600 Kha $y^{-1}$ plus 600 Kha $y^{-1}$<br>actual: 2.2 Mha $y^{-1}$ affor |
| | | 2010-2015 | target: 2.5 Mha affor plus 2.5 Mha restor[8]<br>actual: 4.0 Mha affor | 2010-2015 | target: 500 Kha $y^{-1}$ plus 500 Kha $y^{-1}$<br>actual: 800 Kha $y^{-1}$ affor |
| | | 2000-2015 | 20.8 Mha affor | 2000-2015 | 1.4 Mha $y^{-1}$ affor |

| Measure | Pattern | Quantitative Estimates | | | | | |
|---|---|---|---|---|---|---|---|
| **Forest Stocks, Carbon and Emissions** | | | | | | | |
| | | Absolute | | Absolute Change | | Rate of Change | |
| Forest growing stock volume[9] | Stable total volume with decreasing volume/ha from 1992-2002, both decreasing thereafter | 1992 | 4.74 $Bm^3$; 74.2 $m^3$ $ha^{-1}$ avg | 1992-2013 | Loss of 546 $Mm^3$ over 21 years<br>Decline of 14.4 $m^3$/ha average | 1992-2013 | Loss of 26 $Mm^3$ $y^{-1}$<br>Decline of 0.7 $m^3$ $ha^{-1}$ /yr avg |
| | | 2002 | 4.78 $Bm^3$; 70.5 $m^3$ $ha^{-1}$ avg | | | | |
| | | 2013 | 4.20 $Bm^3$; 59.8 $m^3$ $ha^{-1}$ avg | | | | |
| Net forest sequestrations[10] | Government data show forests becoming a strong sink from the mid-1990's | 1994 | 22.3 $GtCO_2$ stock[11] | 1994-2004 | 2.17 $GtCO_2$ sink (120 $MtCO_2$)[12] | 1994 | 5.5 $MtCO_2$ $y^{-1}$ sink[13] (6.3 $MtCO_2$ $yr^{-1}$) |
| | | 2004 | 24.4 $GtCO_2$ stock | | | 1994-2004 | 217 $MtCO_2$ $y^{-1}$ sink (12 $MtCO_2$ $yr^{-1}$) |
| | | 2011 | 25.5 $GtCO_2$ stock | 2004-2011 | 1.02 $GtCO_2$ sink (242 $MtCO_2$) | 2004-2011 | 146 $MtCO_2$ $y^{-1}$ sink (34.6 $MtCO_2$ $yr^{-1}$) |
| | | 2013 | 25.8 $GtCO_2$ stock | | | 2011-2013 | 189 $MtCO_2$ $y^{-1}$ sink (20 $MtCO_2$ $yr^{-1}$) |
| | | | | 2011-2013 | 38 $MtCO_2$ sink (40 $MtCO_2$) | | |

| Measure | Pattern | Quantitative Estimates | | | |
|---|---|---|---|---|---|
| **Cost** | | | | | |
| | | Absolute | | Per ha, year and $tCO_2$ | |
| Budgetary cost and future estimates | NA | 1980-2002 | Rp 76.3 billion, ~$5.8 billion[14] | 1980-2002 | Rp 2800 $ha^{-1}$; ~$215 $ha^{-1}$ |
| | | 2002-2007 | Rp 11.8-29.6 billion, ~$321-807 million | 2002-2007 | Rp 1100-2700 $ha^{-1}$, ~$30-74 ha |
| | | 2014 (2020) | Rp 107 billion $y^{-1}$ [15], $1.8 billion $y^{-1}$ [16] | 2014 (2020) | Rp 22,800 $ha^{-1}$; ~$382 $ha^{-1}$ |
| | | | | 1992-2002 spending versus 1992-2002 sequestration:[17] | ~$1-2.50/$tCO_2$ |

[1] Assuming India's proportion of South Asia's forests was constant from 1700 to 1880, using Ramankutty and Foley (1999) for South Asian forest area from 1700 and 1880 and Tian et al (2014) for India's forest area in 1880.

[2] All estimates in this row after 1982 are from various years of the Forest Survey of India (FSI).

[3] Afforestation area and forest cover statistics used for this row are all from the Government of India. Independent studies show mixed support for India's forest cover and forest cover change statistics.

[4] Data from Eighth FYP, representing First through Fifth FYP periods prior to acceleration of afforestation efforts.

[5] Data from Eighth FYP through 1990, and from Ravindranath et al 2008 for 1991-2002.

[6] Goals of the National Afforestation Programme as cited by the BUR (2015).

[7] Actual afforestation from BUR (2015) for 2000-2015.

[8] Targets of Green India Mission for 2010-2020.

[9] Growing stock volume data from FSI reports. Average volume per hectare calculated as total growing stock volume divided by forest cover. India's reports of growing stock to the FAO show an increasing rather than decreasing trend from 1990 to 2010. Growing stock volume of trees outside forests (TOF) excluded, but show the same general decline in FSI data.

[10] This row shows data from India's FSI reports. Alternative estimates based on Government of India data also show a strong sink. Two independent studies that do not rely on FSI forest cover estimates find that India's forests are a source rather than a sink.

[11] This sub-row is based on carbon stock reported for India's forests by FSI reports for all five carbon pools (AGB, BGB, deadwood, litter, and soil carbon), and the differences in those carbon stocks.

[12] Estimates in parenthases are from Houghton, R.A., and A.A. Nassikas (2017). *Global and regional fluxes of carbon from land use and land cover change 1850–2015*, Global Biogeochemical Cycles 31:456-472, doi:10.1002/2016GB005546. Country-level data were developed in the article cited (but unpublished).

[13] The total of forest fluxes from India's 1994 GHGI reported in its First National Communication to the UNFCCC is included. It includes the sum of changes in forest and other woody biomass, forest and grassland conversion, and abandonment of managed lands, assuming that most of the latter two categories are forest-based emissions.

[14] Dollar values are based on converting rupees to dollars according to average annual exchange rates at the time of expenditures, and using US GDP-inflators to adjust to 2016 real dollars.

[15] Expert Group on Low-Carbon Growth (2014) annual estimates for post-2020 forest sector action including for 1 Mha y-1 of afforestation, 2 Mha y-1 of forest restoration, and 1.7 Mha y-1 of afforestation in forest fringe villages.

[16] The Expert Group on Low-Carbon Growth suggests that the three afforestation actions taken together would sequester an additional 34.5 $MtCO_2$ y-1, which at $1.76 billion per year suggests an average mitigation cost of $51/$tCO_2$.

[17] With large fluctuations in both cost and mitigation, this rough estimate is based on a range of averages across different periods and government-based sources.