RESTORE+

Mid-Term Report

Addressing Landscape Restoration for Degraded Land in Indonesia and Brazil

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based on a decision of the German Bundestag

The RESTORE+ project is implemented by the International Institute for Applied Systems Analysis (IIASA), World Agroforestry Centre (ICRAF), Brazil National Space Research Agency (INPE), Brazil Institute for Applied Economic Research (IPEA), UN Environment-World Conservation Monitoring Centre (UNEP-WCMC), World Resources Institute (WRI) Indonesia, World Wildlife Fund (WWF) Indonesia, Mercator Research Institute on Global Commons and Climate Change (MCC), Environment Defense Fund (EDF) and London School of Economics (LSE) Grantham Research Institute on Climate Change and the Environment.

The project is part of the International Climate Initiative (IKI). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag.

Executive Summary

- Restoration of degraded land, as recently underlined by the declaration of the UN Decade on Ecosystem Restoration, is a significant contributor to the global effort of enhancing land use sustainability and addressing multiple related challenges such as the climate crisis.

- However, interventions and approaches differ widely, due to the diverging perceptions of degradation as motivation for restoration. Additional complexity arises through the need of landscape restoration to address contextual specificities and a range of interlinked practical challenges. This leads to the question as to how diverse and site-specific restoration activities contribute to the aspirational targets of national/global restoration efforts.

- **The RESTORE+ project** addresses restoration potential with a comprehensive assessment of degradation and restoration, combining the identification of degraded areas, multi-objective modelling and trade-off analysis. Striving to reconcile regional (landscape) heterogeneity with efforts to inform large scale restoration policies, the project aims at enhancing land use planning capacity related to restoration or utilization of degraded areas in Indonesia and Brazil.

- The project integrates biophysical aspects of degradation with social, policy and conservation dimensions by including enhanced datasets gained from novel mapping approaches into biophysical modelling, economic land use modelling and biodiversity impact assessment. Further, the potential of scalable financing mechanisms for restoration are examined.

- **In Indonesia,** RESTORE+ combines participatory mapping campaigns with biophysical and land-use modelling. The aim is to identify specific areas with scenarios for restoration and their implications on production, biodiversity, greenhouse gas (GHG) emissions and social impacts.

- The first half of the project focussed on building foundations for in-depth restoration assessment. Assessing restoration potential at national scale in Indonesia requires land cover mapping products that have sufficient spatial resolution and thematic resolution. This includes developing and adjusting various analytical tools, policy review and analyses, building crowd-empowered data collection platform, conventional data collection, as well as crowdsourcing campaigns.

- As next steps, finalization of land cover mapping will be followed with the identification of large-scale restoration potential. The identification method will be based on potential landscape interventions to accommodate the heterogeneity of degradation and restoration objectives across different areas in Indonesia.

- RESTORE+ used process-based models to assess vegetation and agriculture productivity of restoration interventions based on the landscape's biogeochemical, hydrology and climatic properties. This provided insights on potential yields of commercial commodities and carbon stock of forest areas.

- Land-use economic modelling was also conducted to incorporate mapping and biophysical productivity information into scenario analysis looking at national land use projections to inform low carbon interventions in the Low Carbon Development Indonesia (LCDI) initiative. Led by the Ministry of National Development Planning (Bappenas), the LCDI initiative informed the formulation of the RPJMN 2020-2024.

- **In Brazil,** RESTORE+ enhances established land monitoring and modelling capabilities and supports Brazil's contribution to meeting the Bonn Challenge. The project therefore identifies degraded areas, assesses restoration options and explores trade-offs associated with the implementation of the Brazilian Forest Code (FC).

- Machine learning is used to combine land use samples and satellite image time series for mapping land cover and land use. The results enable informed assessment of the interplay between production and protection in the Amazon and Cerrado, supporting land use and cover planning and public policies.

- As the future demand for ethanol in Brazil has a direct impact on land use, in RESTORE+ estimates three different scenarios of ethanol demand towards 2030. The results indicate that increased demand would insignificantly affect area or production of other crops. The expansion is expected to take place mainly over pasture and to a lesser extent over non-productive lands. This suggests that Brazil could meet future demand for ethanol with limited effects on other crops and native vegetation if the ethanol industry continues to follow the sugarcane agroecological zoning.

- Biodiversity analysis constitutes an important element in the assessment of restoration options in Brazil. The first model runs for species habitat change 2020 to 2050 and biodiversity intactness showed that the implementation of the Forest Code aids biodiversity. However, biodiversity results can be improved through the removal of the small farms amnesty and/or the compensation of environmental debt.

- For the forest-rich countries of **the Congo Basin** - different to other tropical countries such as Brazil and Indonesia - halting deforestation is of utmost importance, where restoration still plays a minor role. Building on existing land use change projections, RESTORE+ applies its tools and incorporates newly available datasets on degraded areas, for land cover development and national forest inventory to develop improved land cover change maps and emission factors.

- RESTORE+ will continue to address the two fundamental questions of restoration with approaches that are inclusive to the heterogeneity of landscape degradation and restoration potential, as well as diverse interventions that will be specific to site-specific socio-ecological restoration objectives.

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1. Introduction

On March 1st, 2019 the UN General Assembly declared the UN Decade on Ecosystem Restoration, stressing its unprecedented importance at the time of completing the second year of the RESTORE+ project. The UN Decade aims at massively scaling up the restoration of degraded and destroyed ecosystems as a proven measure to fight the climate crisis and enhance food security, water supply and biodiversity. Already before, the recognition of the significance of restoring deforested and degraded areas empathized by the declaration, is reflected in a variety of international programs and framework strategies, such as the Bonn Challenge, the Convention on Biological Diversity (CBD) Aichi Target 15, the Rio+20 land degradation neutral goal and the United Nations Framework Convention on Climate Change (UNFCCC) Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+) goal.

Moreover, both focus regions of the RESTORE+ project, Indonesia and Brazil, have ambitious restoration related policies in place. Indonesia's Climate Resilience Strategy mentions both reduction in forest degradation and utilization of degraded land for renewable energy as enhanced action priorities. At the same time, these measures are closely related to the land reform target of reallocating 9 million hectares (Mha) to marginalised people. Indonesia also has a national target to rehabilitate 5.5 Mha of degraded forests and land, and the newly established Peat Restoration Agency has the mandate to restore 2 Mha of degraded peatlands by 2020.

Brazil has made a commitment to the UNFCCC to restore 12 Mha of deforested areas by 2030. Moreover, restoration – particularly through reforestation – is an important element of the Brazil's Forest Code, which consists of innovative policy instruments such as the Rural Environmental Cadastre.

Restoration on a landscape-level involves the presence of diverse and numerous stakeholders and complicated interactions of multiple measures. Questions may arise as to how these site-specific restoration outcomes contribute to ex-ante targets of national/global restoration efforts. Therefore, ensuring effective and sustainable results may require the application of multiple measures that suit the varying needs of stakeholders. An inclusive and participative process is clearly essential, since restoration strategies need to consider specific needs of ecological functions, local rights and values, as well as other socio-ecological contexts.

Now, halfway into the project, this report intends to provide a summarizing review of the first half of the project and presents first interim results on how the project approaches the complexity of restoration efforts. This is partially based on presentations, discussions and feedback given during the project's mid-term meeting in Foz do Iguaçu from 25-27 September 2019. On this occasion, the project's consortium invited national stakeholders from Brazil, government representatives from Indonesia, as well as representatives of the broader international restoration community.

During the three-day meeting, hosted by INPE and IIASA, the consortium partners presented country specific project approaches and preliminary results. In addition to present and discuss the project's progress of the last few months, the project consortium also engaged in open discussions with invited participants from Brazil and Indonesia. Not only to inform but also aiming at consulting these stakeholders about project relevance and potential contribution to evidence-based policy making processes and discuss potential contribution to regional and global restoration initiatives.

This report contains preliminary results and reflections on progress and status quo. Finally, the report concludes with feedbacks and discussions on existing challenges faced by the project, and gives an outlook on the corresponding necessary learnings and next steps for the second half of the project.

2. The RESTORE+ project

RESTORE+ is a five-year partnership that aims at enhancing land use planning capacity related to restoration in Indonesia and Brazil. In Indonesia, the project combines participatory mapping campaigns with biophysical and land-use modelling. The aim will be to identify specific areas with scenarios for restoration and their implications on production, biodiversity, greenhouse gas (GHG) emissions and social impacts. In Brazil, the project will enhance established land monitoring and modelling capabilities and support Brazil's contribution to meeting the Bonn Challenge. The project will identify degraded areas, assess restoration options and explore trade-offs associated with implementation of the Brazilian Forest Code.

2.1 Problem statement

Restoration of degraded land is a significant contributor to the global effort of enhancing land use sustainability. However, landscape restoration needs to address context specific complexities and a range of interlinked practical questions and challenges. The approaches that the different landscapes require will differ in their definitions and understandings of degradation and restoration. Consequently, the emphases on how to comprehensively address multiple ecosystem services and socio-economic concerns of these landscapes also vary. On the other hand, due to the aspiration to inform large scale restoration policies, i.e. those with national or regional scope, generating operational insights also requires sufficient representation of the heterogeneity of various landscapes within the country boundaries. Putting too much emphasis on certain characteristics or restoration objectives that form the complexity of a particular landscape might undermine the complexity of other landscapes. Examining the fundamental questions of restoration becomes important in the effort of striking a balance between complexity and heterogeneity.

The first question to be addressed concerns what should be subjected to restoration activities. Answering this question can be challenging due to the discrepancy in perceiving and understanding degradation as the motivation for restoration. Common understanding on what or where to restore suffers from existing discrepancies in degradation definition as various forms and intensities of how landscapes deviate from expected socio-ecological functions. Lack of robust and operational definition of degradation have significant contribution to these discrepancies. Many definitions are either too inclusive and therefore reductionist in nature, or subject to flexible interpretation. Varying technical perspectives also led to the failure of experts in agreeing upon a single definition of degradation, or to be specific in defining its scope. Global studies that attempted to map the world's degraded land have revealed the enormous challenge in addressing this issue for large scale assessments. The studies refer to different measurable features of degradation, quality of datasets and spatial coverage. Results from these studies differ significantly in quantity, up to more than 600%, as well as in spatial distribution of the identified degraded land (Safriel 2007; Gibbs and Salmon 2015).

The next fundamental question to be addressed concerns how restoration should be conducted, in light of various uncertainty related to the potential areas to be restored. What are the landscape interventions that constitute restoration activities? How do they perform overtime? How will such performance compare from a socio-ecological standpoint against alternative measures that might take place instead of these specific landscape interventions?

Restoration interventions depend on the state of the landscape to be restored, as well as the expected outcome of implementing restoration activities. Intervention options may also change overtime as measures that have been previously implemented already result in a better ecological state hence allowing the landscape to 'elevate' to a different expected outcome in terms of biodiversity and ecosystem services. 'Elevation' along the restoration staircase (Figure 1) also represents the temporal dimension of restoration, which is another important element in large scale restoration assessment.

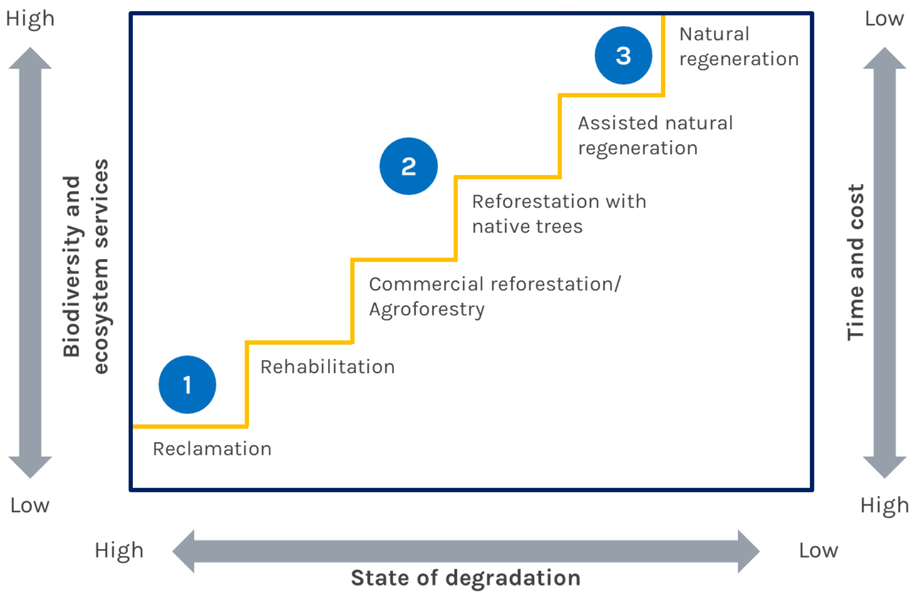


Figure 1 Restoration staircase (Chazdon 2008) which describes the type of interventions depending on the state of degradation, required time and cost, and level of restored biodiversity and ecosystem services. Outcome of particular interventions are (1) soil fertility, (2) timber and/or non-timber forest products and (3) recovery of biodiversity and ecosystem services.

It is then important to understand how these interventions perform on different locations, with different agroecological conditions, over a period of time that covers relevant milestones of ecological succession resulting from restoration. It is also worth noting that understanding the theoretical performance alone may not be sufficient. Informing decision makers that are concerned with particular landscapes requires analyses that also take into account alternative land uses that might unfold, or even preferred, over restoration interventions.

2.2 Project goals

The objective of the project is to provide decision makers in the tropical region with lasting capacity, technical recommendations, and enhanced datasets to inform the restoration of degraded and marginal areas. This calls for a comprehensive assessment of degradation and restoration, which requires the identification of degraded areas, multi-objective modelling and trade-off analysis. It provides the opportunity to develop a generic methodology that can be applied to other regions in order to maximise the impact of the results. To this end, while focusing on detailed assessment activities in Indonesia and Brazil, the project also covers the Congo Basin, to conduct dissemination and research outreach activities in this area.

Specifically, the project aims to generate information, tools and understanding on: 1) the extent and distribution of degraded land, 2) the socio-economic and environmental (e.g., GHG emissions and biodiversity) implications of varying definitions, and related uses, of degraded land, and 3) the options and trade-offs for ecosystem restoration or sustainable food/energy crop production on degraded lands.

In **Indonesia**, RESTORE+ aims to use the above to inform key national and sub-national policies. Relevant national policies that are targeted to utilize such information include the medium-term economic development plan, nationally determined contribution, climate resilience strategy, and national biodiversity strategies and action plan.

Other than results, the project will also deliver modelling tools that can be used for further analyses or other related inquiries in the broader land use context. As model development and modelling assessment requires joint capacity building and close collaboration with local stakeholders, enhanced capacity in modelling and analysing results is also a crucial outcome of the project.

In **Brazil**, the project benefits from the results of the preceding IKI-funded REDD-PAC[1] project. Other than generating important technical assessments that are used as the basis of Brazil's NDC, REDD-PAC also resulted in the GLOBIOM-Brazil model and local modelling capacities that will further contribute to RESTORE+. At this stage, the project aims to inform official national documents (e.g., ministry regulations, technical guidelines, policy guidelines) that contribute to the implementation or enhancement of Brazil's Forest Code to help achieve objectives such as those in its NDC and NBSAP.

In the **Congo Basin**, activities are dedicated to gaining endorsement from stakeholders of the region (e.g., Ministries of Forest/Environment, COMIFAC, CN-REDD offices, Ministries of Agriculture) on the potential contribution of RESTORE+ project results to policy formulation or relevant activities of the stakeholders. Selected training activities will also be identified and conducted throughout the project which will result in enhanced capacities.

2.3 Project activities

While technical approaches may vary due to differences in contextual challenges of Brazil and Indonesia, fundamental questions around large scale restoration assessment are addressed in RESTORE+ through three streams of interrelated activities.

The first stream of activities deals with the issue of **restoration area identification**. The RESTORE+ team in Brazil benefits from the country's advanced earth observation infrastructure and dataset availability. In Brazil, restoration area is identified through analysing a time-series multi-dimensional stack of remote sensing data. Moreover, to also align with national policies, restoration potential is

[1] See www.redd-pac.org for more information.

further examined using information from the Rural Environmental Registry (or *Cadastro Ambiental Rural* (CAR)) that was available since 2012. In Indonesia, due to geographical challenges, such as constantly high amount of cloud cover and heterogeneity of land use practices throughout the archipelago, RESTORE+ relies on mapping approach that utilizes crowd-generated datasets and open-source platforms to allow contribution from both the restoration community as well as broader general public.

Approaches to identify restoration potential in Brazil and Indonesia also differ in their understanding of areas that are subjected to restoration. Brazil benefits from having issued policies with clear objectives and scope of restoration activities. Hence, identifying potential areas for restoration in Brazil heavily relies on formulations in these policies. In Indonesia, a more inclusive approach is required as the country has multiple policies with different restoration goals that target distinct forms of landscape degradation. Such a challenge is also better addressed using an approach that relies on stakeholder contribution and allows continuous improvement as policy discourse around the issue of restoration advances.

The second stream of activities deal with assessing the theoretical performance of **restoration interventions**. Process-based models are used to assess the biophysical potential of various restoration interventions based on climatic and biogeochemical properties of focus areas in both countries. In Brazil, special emphasis is given to examining climate change impact towards biophysical productivity of key commodities which will in turn influence future land use and land cover change. Such an analysis will inform potential pressure for land demand which directly competes with areas that are suitable for restoration. In Indonesia, biophysical productivity is modelled for a wide range of restoration interventions in both peat and non-peat areas which include native species, agroforestry systems and commercial tree species.

Finally, the third stream of activities uses insights from other streams by analysing the trade-off among various **restoration scenarios**, each based on different option for of restoration areas and interventions. Insight and policy recommendations will be drawn relying on land use economic analysis informed by remote sensing and biophysical productivity datasets. Biodiversity assessment will also be conducted for all restoration scenarios to complement insights on ecosystem services such as agriculture and forestry production (provisioning services), as well as land cover change and carbon accumulation (regulating services).

3. RESTORE+ in Indonesia

The first half of the project was dedicated to building foundations for in-depth restoration assessment in Indonesia. This includes developing and adjusting various analytical tools, policy review and analyses, building crowd-empowered data collection platform, conventional data collection, as well as crowdsourcing campaigns. Stakeholder consultations were conducted in the initial stage of the activities, followed by technical work and iterative process for continuous stakeholder engagement.

During this period, RESTORE+ also contributed to the modelling activities of the Low Carbon Development Indonesia (LCDI) initiative led by the Ministry of National Development Planning (Bappenas), particularly in providing insights related to land sector projections. This interaction is followed with a more focused investigation on the impact of increasing land productivity of key agricultural commodities, also facilitated by Bappenas. These activities allowed the project to contribute to the formulation of the National Medium Term Development Plan 2020-2024 throughout 2017-2019. Both activities also contributed to national downscaling and adjustments of various models used in the project (chapter 3.2 and 3.3) for further usage in combination with other streams of activites.

3.1 Mapping and identification of restoration potential

Indonesia is home to the world's third largest tropical rainforest, after Brazil and the Democratic Republic of Congo. In Indonesia, the area designated as *forest area* or *forest estate* (in Indonesian, *Kawasan hutan dan perairan*) which covers 125.9 Mha (Subdirektorat Jaringan Data Spasial 2018), are managed with regards to its designated function, whether for protection, conservation, or production. Notably, the area designated as *production forest* constitutes the largest share (68.8 Mha, or 54.7%) of the total *forest area* (Subdirektorat Jaringan Data Spasial 2018). The designated function, however, does not necessarily describe the actual condition or biophysical cover of the land, or in other words, the actual *land cover*. At present, the designated *production forest* area is fragmented into a mosaic of a variety of land cover types, such as undisturbed or primary forest, logged-over forest, unproductive forest (e.g. previously burnt area), shrub, and grassland (Wijayanto 2017). In addition, the production forest area is also fragmented into various *land use* types, such as mining, monoculture, and local people settlement. The reality is, the productivity and ecological status of the forest area has continued to deteriorate due to human activities such as illegal logging and land conversion on one hand, while on the other hand, a large part of the forest area is currently not managed or optimally managed (Wijayanto 2017), hence being at risk of illegal extraction activities. For example, out of the 11 Mha area designated for Industrial Plantation Forest concession, the actually planted area was only 4.9 Mha (Wijayanto 2017). Therefore, timely and sufficiently accurate spatially-explicit information (i.e. map) of the actual land cover distribution in the forest area, as well as the non-forest area, is the core data needed for identifying currently degraded or abandoned (idle) area which its ecological status and economic productivity can potentially be restored.

Due to the vast variation in environmental and management practices, assessing restoration potential at national scale in Indonesia requires land cover mapping products that have sufficient spatial resolution and thematic resolution. Publicly accessible products for the region arguably have not met these requirements, in order to be effectively used by the national and sub-national end users or stakeholders (Miettinen, Shi, and Liew 2019). In particular, the thematic detail i.e. the land cover classification scheme (typology) has to be designed to be nationally relevant, in order to meet the actionable information needs of the stakeholders involved in landscape restoration planning and implementation.

In this stream of work, activities in the first half of the project were dedicated to methodological development for machine learning based mapping product that allows participatory process involving national and sub-national end user groups and stakeholders in discussion, consultation, and capacity building. Such approach aims to optimally combine the *digital mapping* approach and *knowledge mapping* approach, *best science,* and *best knowledge*, as recommended in the restoration opportunities assessment methodology (ROAM) by IUCN & WRI. Particularly the *knowledge mapping* approach, by facilitating the transfer of local knowledge from different stakeholders into the digital mapping products, is beneficial in Indonesia context due to the limited availability of (accessible) digital maps, especially those which have countrywide coverage and which are regularly updated.

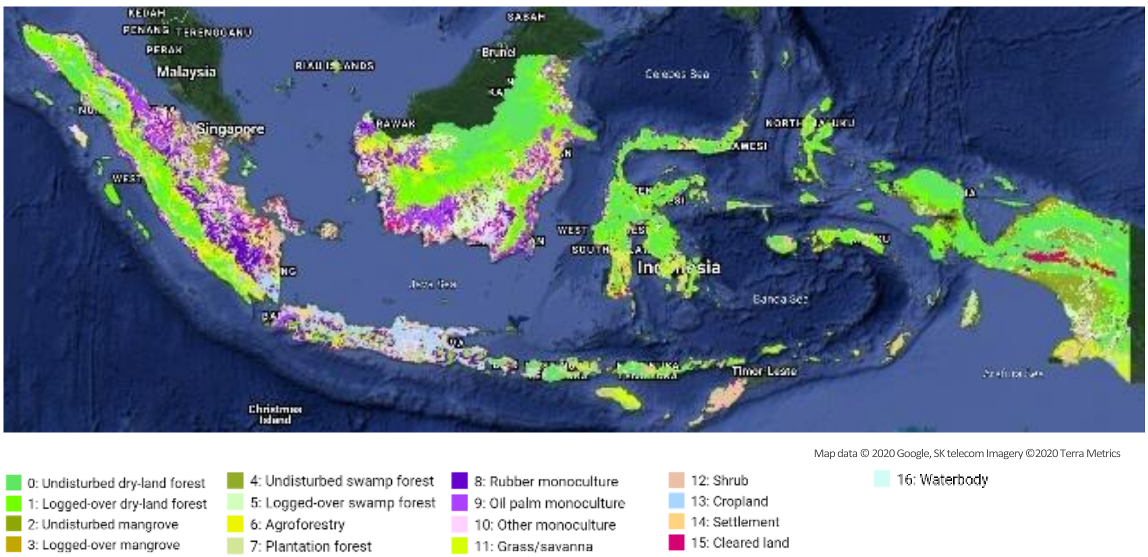


Figure 2 Experimental countrywide land cover map at 100 m resolution generated by automated supervised classification in Google Earth Engine cloud-based platform. Source: RESTORE+ preliminary result

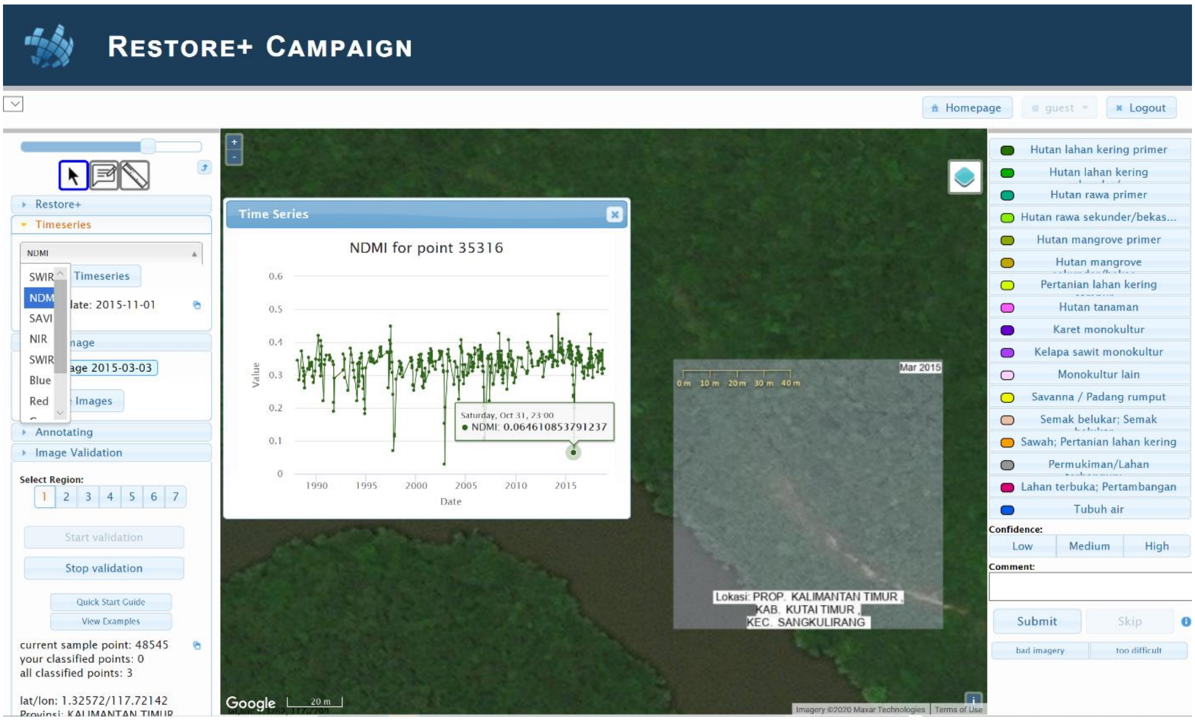
Towards the national scale assessment of restoration potential in Indonesia, a countrywide land cover map for the year 2018 is being produced (Figure 2). The 2018 map, together with the available reference land cover map for 2010, will allow the assessment of restoration potential, via changes in land cover types between the year 2010 and 2018. Resources permitting, the national scale land cover map will also be produced for the year 2015, recognizing the pattern of land cover dynamic between 2015 and 2018 likely differs from the dynamic between 2010 and 2015. This is expected because the record-breaking fire season in 2015 prompted the central government to implement some changes in land use policies, such as the extension of moratorium on new permits on primary forest and peatlands.

In terms of the required thematic resolution, the classification scheme was designed together with the country partners so that the typology has the appropriate level of details for restoration assessment at national scale, and is compatible with existing classification scheme such as the Indonesian National Standard on high and moderate resolution land cover classification. Specifically, the determined land cover classes are *undisturbed forest, logged-over forest, agroforestry, plantation forest, rubber monoculture, oil palm monoculture, other monoculture, grass and savannah, shrub, cropland, cleared land*, and *other land*. Agroforestry, the practice of combining trees and/or shrubs with crops and/or livestock, despite the likely challenge in mapping it, is included in the typology due to its increasingly recognized importance as a land use system to help make monoculture area to be more environmentally sustainable, climate friendly, and economically productive, as an integral part of a more sustainably managed ecosystem. A spatial resolution of 100 meter (1 hectare) was determined, which is considered sufficient for the national scale restoration assessment, as well as matches the 2010 reference land cover map, while a temporal resolution of 1 year (annual) was specified.

Given the scale and scope of the land cover mapping products required here, an automated supervised classification approach using the state-of-the-art machine learning techniques and cloud computing technology was opted. The digital mapping algorithm is being developed on the Google Earth Engine (GEE) cloud-based platform (Gorelick et al. 2017), which is now freely available to academic, NGO, and public sectors. GEE is a cloud-based platform that facilitates easy access to Google's high-performance computing resources and the multi-petabyte catalogue of satellite imagery and geospatial datasets in its public data archive. The supervised classification approach benefits from the readily available reference land cover map with national coverage and sufficiently detailed spatial (100 meter) and thematic resolution (20 classes) for the year 2010 from ICRAF. In terms of spatial unit of the mapping, pixel-based approach was used as the alternative computationally very expensive object-based approach, at national scale.

The following briefly describes the mapping methodology. Firstly, the input data (predictors/covariates) used for the land cover classification includes optical data from Landsat satellites, radar data from PALSAR-2 and Sentinel-1 satellites, as well as digital elevation dataset from the Shuttle Radar Topography Mission. Secondly, the random forest algorithm is chosen for the supervised classification. Random forest is widely used in land cover mapping using satellite data, owing to its desirable properties namely it is robust to label noise and outliers, interpretable, and relatively stable with the choice of hyperparameters, which makes it suitable for operational processing chains (Pelletier et al. 2016; Inglada et al. 2017). The random forest algorithm was trained using satellite data composites for the same year as the reference map (2010), except for the Sentinel-1 data for which the 2018 composites were used. In order to allow the 2018 Sentinel-1 data to characterize the land cover classes in the 2010 map, only pixels in the reference land cover map that are identified as not having experienced tree cover loss between 2010 and 2018 (based on Hansen et al. 2013 dataset) were sampled as classifier training data. To account for the geographical variability in the biophysical characteristics (and hence spectral and backscatter signatures) of the same land cover classes, due to ecological and management differences, the classification model was trained and applied separately for seven regions based on main island groups of Sumatera, Kalimantan, Java-Madura-Bali, Sulawesi, Maluku, East and West Nusa Tenggara, and Papua.

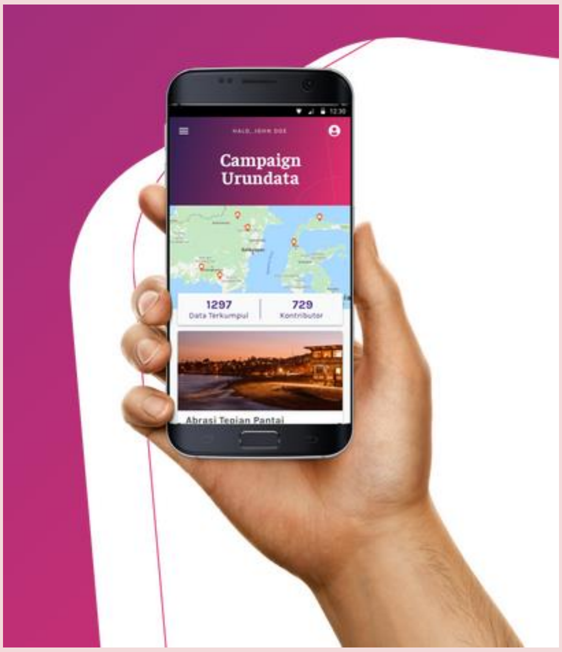
(a)



(b)

Figure 3 (a) Expert knowledge in visual interpretation is incorporated into land cover classification. (b) Web-based tool is utilized to facilitate and document the visual interpretation process.

Further, previous efforts to map large-scale land cover demonstrated the need to introduce expert algorithm/rules/system in the classification process (Miettinen, Shi, and Liew 2019; Souza Jr 2017; Saah et al. 2020). To design the optimal expert rules required in the land cover classification process, the mapping activities seek to gather the knowledge and experience of local mapping experts from different regions of Indonesia (Margono et al. 2016). To this end, a series of expert workshops have been conducted whereby relevant experts from different agencies and different regions were convened to share and discuss their experiences and best practices in land cover mapping activities (Figure 3). The workshops brought together mapping experts from government agencies (such as the regional offices of the Ministry of Environment and Forestry and the Geospatial Information Agency) as well as civil society organizations. The experts came from the western, middle, and eastern region of the country (Sumatera, Java, Kalimantan, Sulawesi, and Papua).



Box 1 Urundata platform — Crowdsourcing for restoration assessment

Impact assessment of large-scale restoration activities requires extensive and geographically diverse set of data. In assessing nation-wide restoration potential, RESTORE+ collaborates with partners at both national and sub-national levels to develop a crowdsourcing platform for data and knowledge accumulation called *Urundata*. The platform provides mobile and web applications to facilitate various groups of stakeholders contribute their technical expertise or observations of the surrounding landscape/environment.

Starting from April 2019, RESTORE+ conducted several crowdsourcing campaigns, mainly targeting university students as contributors, to obtain visual interpretation of high-resolution satellite images. The information is used as reference data for the machine-learning based mapping product to assess nation-wide restoration potential. Through the *Urundata* mobile application, contributors compete in collecting points for every visual interpretation that they contribute. The mobile app uses a gamification approach to allow for more efficient and low-cost approach in data collection while at the same time raises public awareness to the topic of land sustainability. The task in this group of campaigns were designed to have the appropriate level of difficulty to the targeted crowd. The task was also simplified such that the crowd had to only answer “Yes”, “No”, or “Not Sure” to the question of whether they see a particular land cover class in the shown image. To ensure quality, control images that have been validated/interpreted by experts were randomly shown in the application. The users were given feedbacks if they have correctly or incorrectly interpreted the control images, and they were given bonus score or penalty accordingly.

A national scale crowdsourcing campaign was therefore launched in December 2019 and was recently concluded at the end of April 2020. More than 2 million validations were submitted by more than 1000 contributors. The large number of validations allows for higher confidence in the land cover class interpretation by requiring a minimum of 8 validations. Several methods to filter the crowdsourced data based on the estimated accuracy of each contributor, and outlier identification based on satellite measurements, are currently examined. The crowdsourced data would then serve as training data for the selected land cover classes, as part of the overall training dataset required for all land cover classes required for restoration assessment.

Relevance of data and the ability of various groups of contributors to utilize them are fundamental incentives that enables crowdsourcing mechanism to work for data collection. Therefore, *Urundata* also complements crowdsourcing campaigns with joint capacity building activities within the remote sensing community in Indonesia. During these activities, experts discussed technical implementation of the land cover mapping system in GEE that utilizes reference data obtained through crowdsourcing campaigns. The approach aims at building a sustainable model for data collection and processing which can be independently implemented using open-source platforms and data sources.

Learn more about Urundata at https://urundata.id/ and Google Play Store

During the next phase of RESTORE+, the project team will finalize land cover mapping followed with the identification of large-scale restoration potential. The identification method will be based on potential landscape interventions to accommodate the heterogeneity of degradation and restoration objectives across different areas in Indonesia. Such a method will then be applied using land cover changes identified from the land cover mapping activity in combination with other publicly available datasets.

3.2 Assessing theoretical potential of restoration options

Restoration is a long-term process with high uncertainty on its impact towards improvement in ecosystem services and biodiversity. Forest restoration interventions vary. Fast-growing pioneer species can enhance tree cover in a relatively short period but limited in long term impact on carbon sequestration and other aspects of ecosystem services. Interventions with slow-growing species will ultimately deliver more biomass accumulation, but with the obvious timing pitfall leading to high uncertainty and opportunity costs. Moreover, landscape interventions often require agroforestry approach which combines different tree species as well as agriculture crops. Other than enhancing biomass and biodiversity, yield for production is also important to be assessed as restoration will not be sustainable without addressing provision needs for the communities within the landscape.

Within this stream of activity, RESTORE+ utilizes process-based models to provide insights on biomass accumulation of restoration interventions, including productivity of interventions that yield commercial commodities (e.g. timber/fibre production, agriculture crops and non-timber forest products). These models assess vegetation and agriculture productivity of restoration interventions based on the landscape's biogeochemical, hydrology and climatic properties.

3.2.1 Modelling biophysical productivity for national land use scenarios

The first half of the project was dedicated to contributing to the Low Carbon Development Indonesia (LCDI) initiative led by the Ministry of National Development Planning (Bappenas). For this purpose, biophysical productivity of annual and perennial agriculture crops, forestry products and forest regeneration were modelled to provide insights on potential yields of commercial commodities and carbon stock of forest areas. Understanding yield is important as they inform future land demand for agriculture activities. Biophysical modelling also provides information on carbon accumulation of forest regeneration which informs long term climate mitigation impact of restoration and forestry sector development.

Annual crops

Biophysical productivity of annual crops is modelled using the Environmental Policy Integrated Model (EPIC). Initially developed by the United States Department of Agriculture, EPIC is used to compare cropland management systems and their effects on environmental indicators such as water availability, nitrogen and phosphorous levels in soil, and greenhouse gas emissions (Williams et al. 1996). EPIC can analyse several crop types and their management under different weather, topographical, and soil conditions. It investigates the trade-offs between plant growth and yield on the one hand, and environmental impacts and sustainability on the other.

For Indonesia, EPIC was further adjusted with 0.25° (about 27 km at the equator) grid used for linkage with AgMERRA climate dataset, while 5ʻ (about 9 km at the equator) grid was used for spatial harmonization of input data and real pixel areas (100 m x 100 m) for LC statistics. Input datasets include 90 m resolution digital elevation database (SRTM v4.1), Harmonized World Soil Dataset (HWSD v1.0) and ICRAF land cover map.

To inform national scenarios, EPIC models intensified productivity of annual crops for Indonesia. Main assumptions for intensification include fertilization to avoid crop nutrient stress, automatic irrigation to avoid crop water stress where needed, cropping system and improved cultivar. The intensified productivity was modelled for main agriculture commodities i.e. **rice, maize, soybean, cassava, groundnuts, and sugar cane**. EPIC productivity modelling results in productivity datasets that are further used in the GLOBIOM-Indonesia model (section 3.3).

The above assumptions, together with the yield results, are insightful in investigating national scenarios where intensification is expected to ease pressure on land demand and reduce forest conversion. Increasing productivity may require additional input such as fertilization or use of enhanced seeds, but it may also result from increasing cropping index through better management and irrigation. These options are described in Figure 4 where the potential for increasing rice productivity are broken down for every province. The EPIC model investigates main assumptions that form the baseline conditions of agriculture production to mirror yield value provided from the statistics. This provides an understanding on the potential of increasing productivity either by altering the agriculture input, enhancing the cropping index or combination of both.

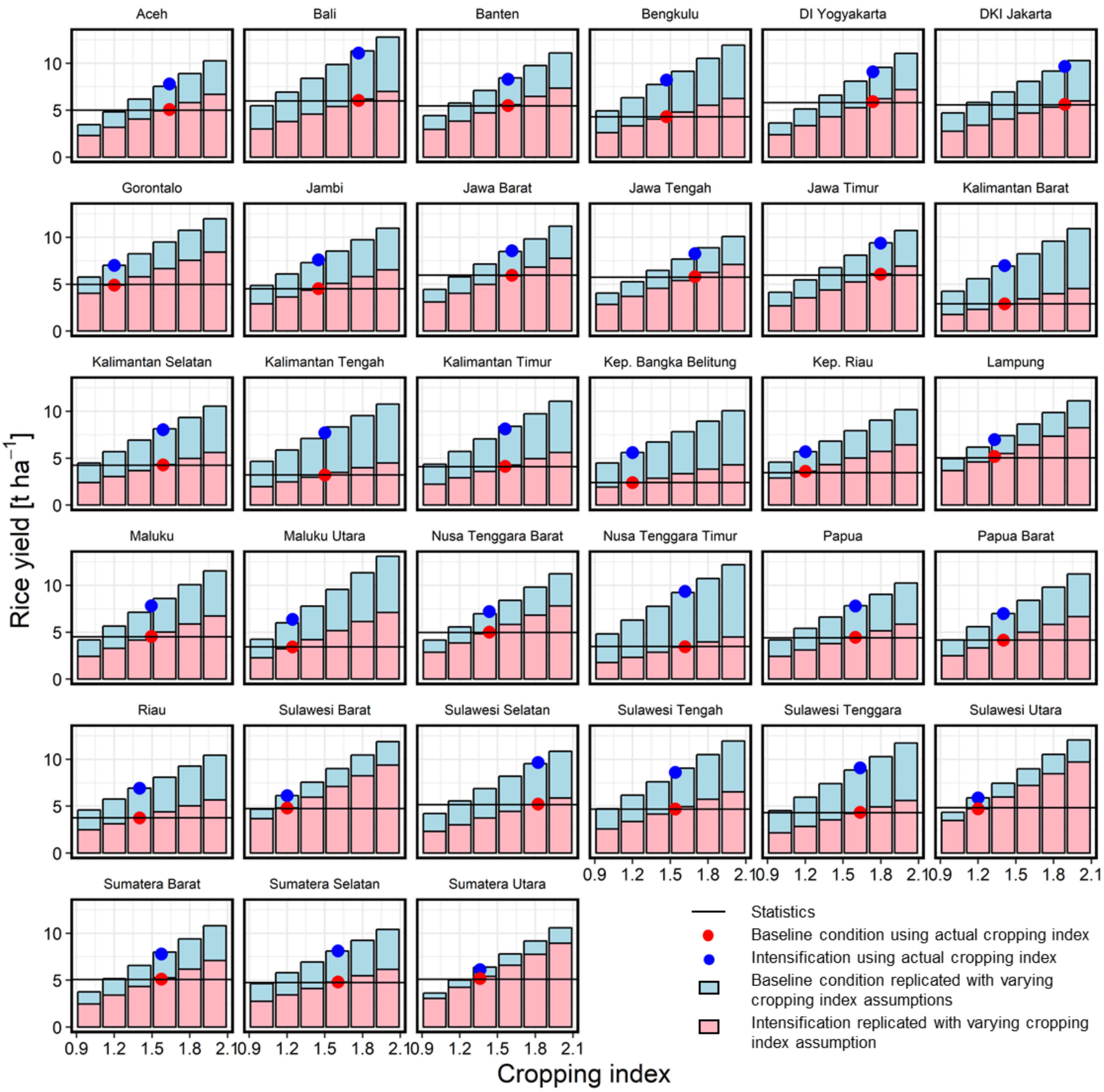


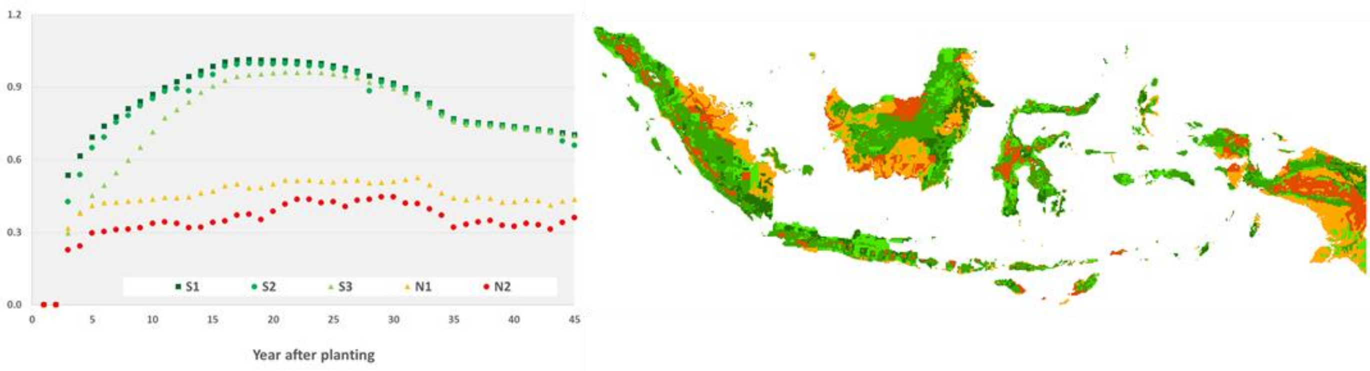
Figure 4 Provincial breakdown of rice productivity (tons/hectare) modelled using EPIC. Source: RESTORE+ preliminary result

Perennial crops

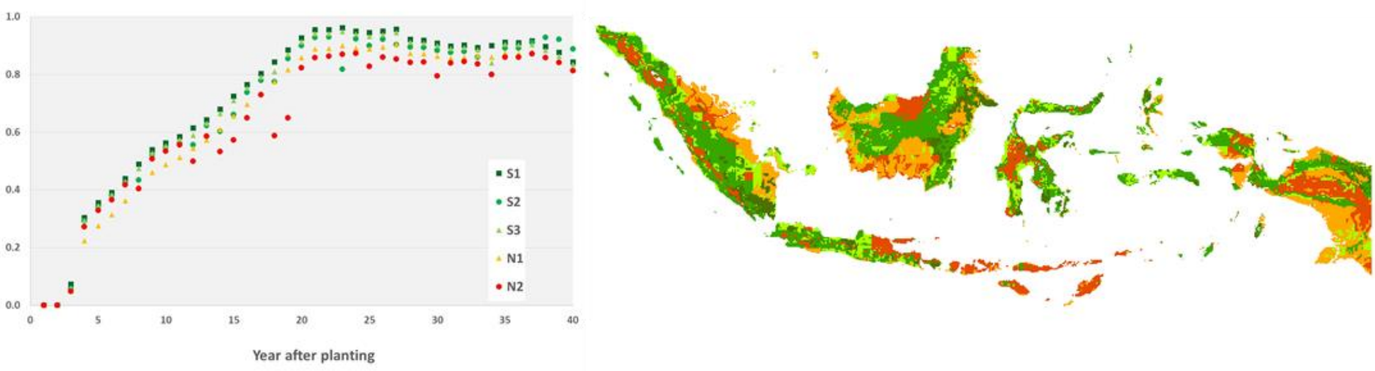
Tree crops are key contributors to land use change in Indonesia. Increasing the productivity of tree crops has been long viewed as a promising measure that can control land conversion while still maintaining reasonable level of economic development. RESTORE+ investigates the main tree crops that play important role in Indonesia's land use sector namely **oil palm, rubber, coffee, cocoa, and coconut**.

The productivity of these tree crops is modelled using the Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model developed by ICRAF. The WaNuLCAS model was developed to represent tree-soil-crop interactions in a wide range of agroforestry systems (Van Noordwijk et al. 2011). The model is based on above and below ground architecture of tree and crop, elementary tree and crop physiology and soil science. In RESTORE+, WaNuLCAS is parameterized using similar setup with EPIC, mainly in the usage of AgMERRA climate datasets and HWSD for soil characteristics. Moreover, land suitability maps for all tree crops were developed using soil and climatic criteria for Indonesia (Hardjowigeno and Widiatmaka 2007).

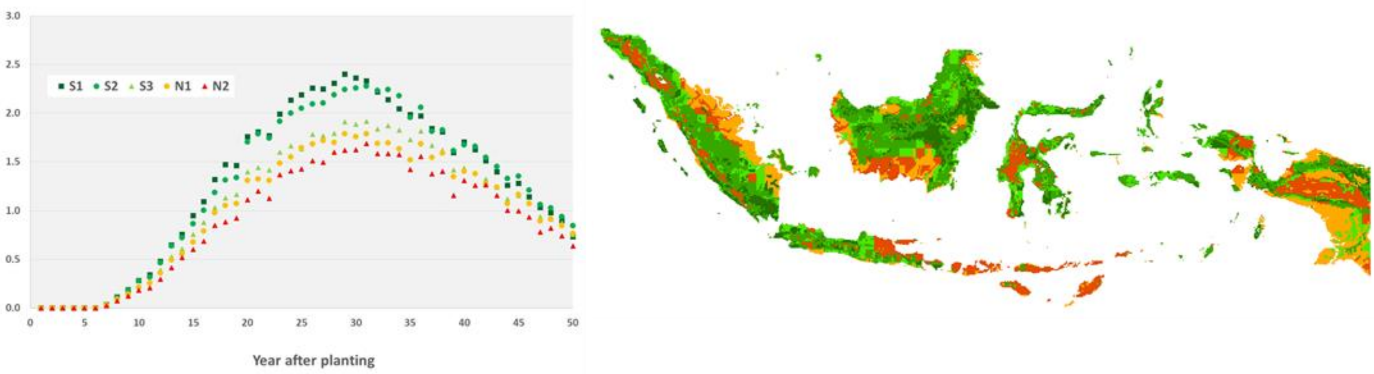
WaNuLCAS modelling results in productivity curves of tree crops according to years of planting (see (b) Oil palm productivity (ton/ha fresh fruit bunch)



(c) Coffee productivity (ton/ha dry bean)

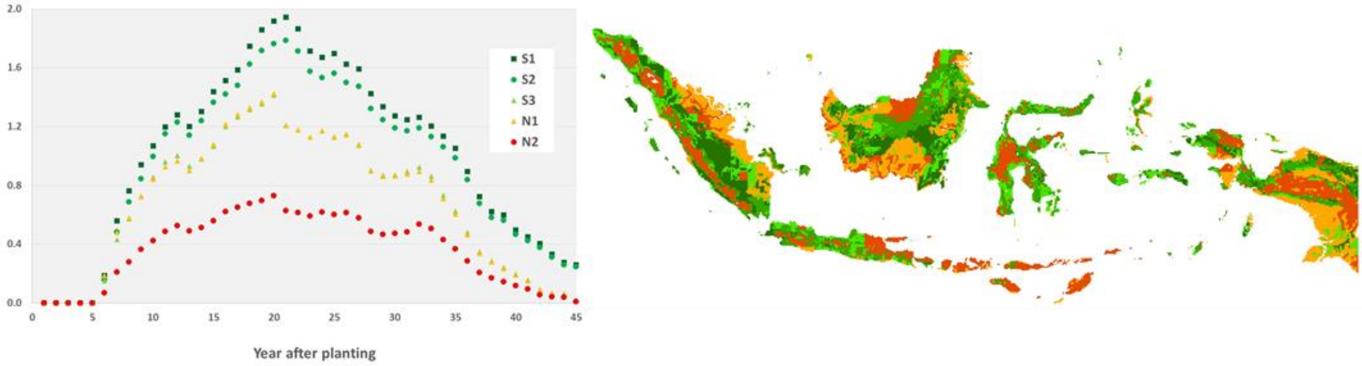


(d) Cocoa productivity (ton/ha dry bean)

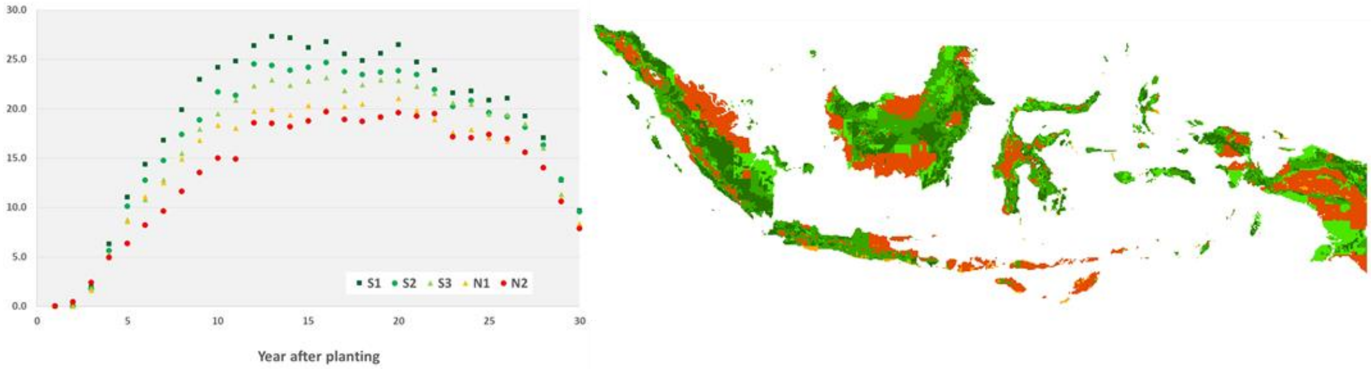


(e) Coconut productivity (ton/ha dry bean)

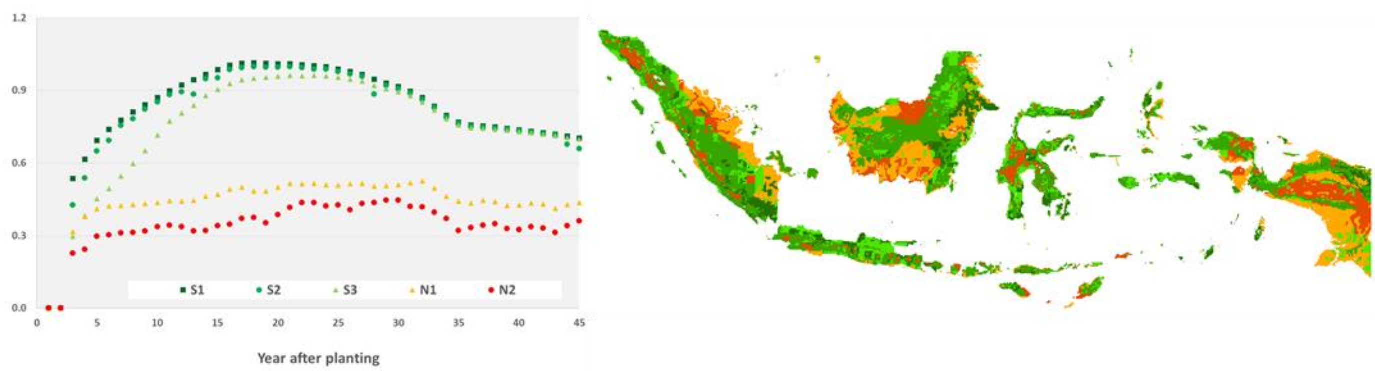
Figure 5). The productivity differs across various locations in accordance with the land suitability maps, taking soil and climate characteristics into account.



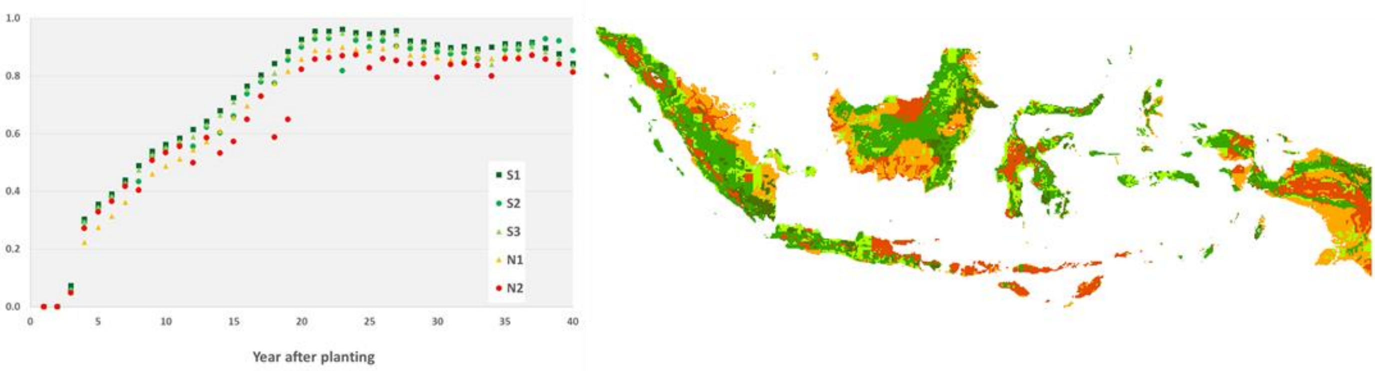
(a) Rubber productivity (ton/ha latex)



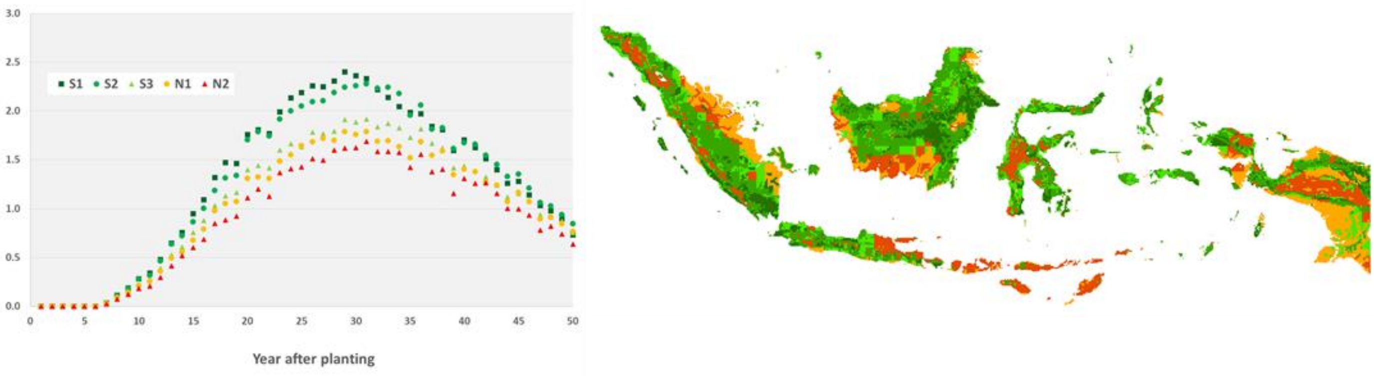
(b) Oil palm productivity (ton/ha fresh fruit bunch)



(c) Coffee productivity (ton/ha dry bean)



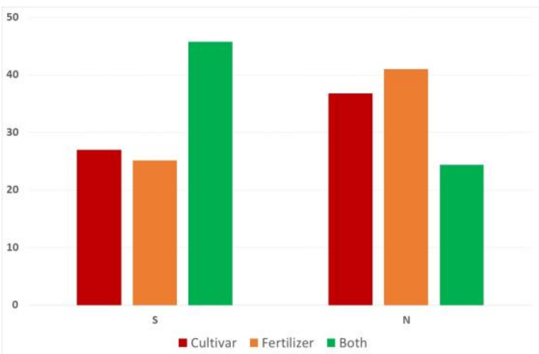
(d) Cocoa productivity (ton/ha dry bean)



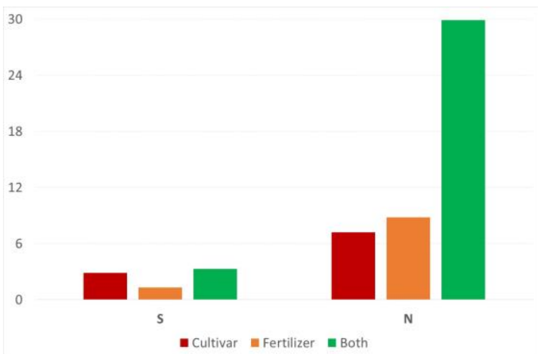
(e) Coconut productivity (ton/ha dry bean)

Figure 5 Productivity of tree crops according to year of planting and their spatial distribution according to land suitability. Land suitability is divided into five classes namely S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), N1 (currently unsuitable) and N2 (permanently unsuitable). Source: RESTORE+ preliminary result

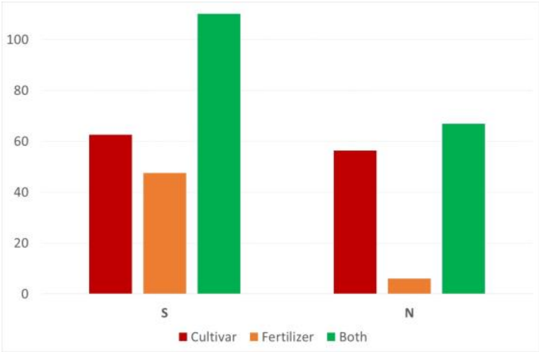
Similar to modelling annual crops, WaNuLCAS also looked into the impact of intensification to productivity. Assumptions for intensification was made in accordance to good agriculture practices guidance from the Ministry of Agriculture (Kementerian Pertanian 2010). Impact of using enhanced seed and increasing fertilization are examined individually and combined (see



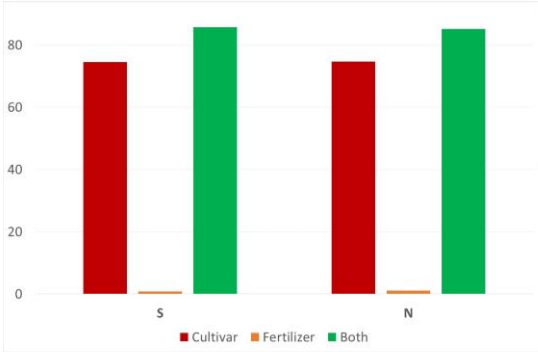
(a) Rubber



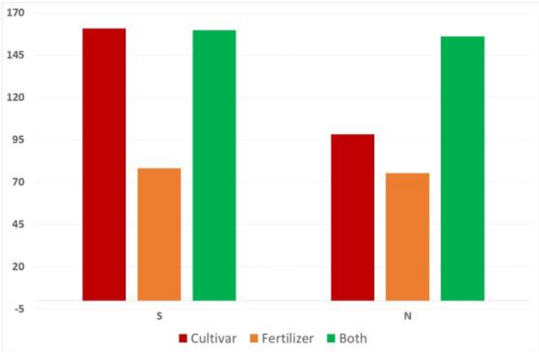
(b) Oil palm



(c) Coffee

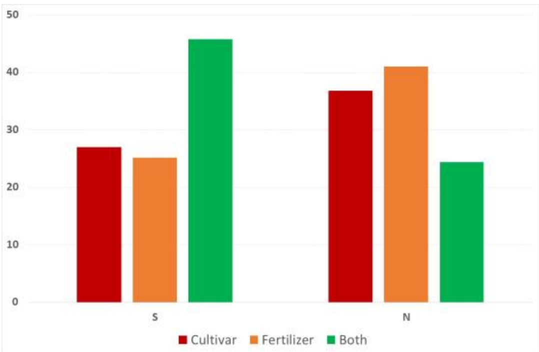


(d) Rubber

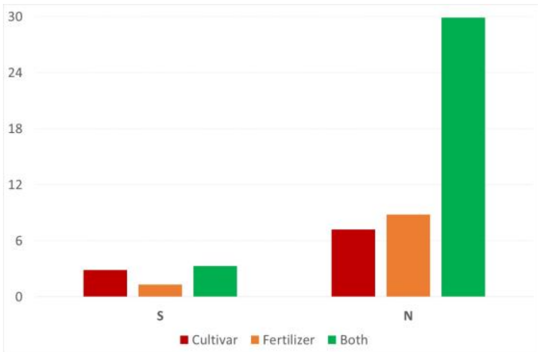


(e) Coconut

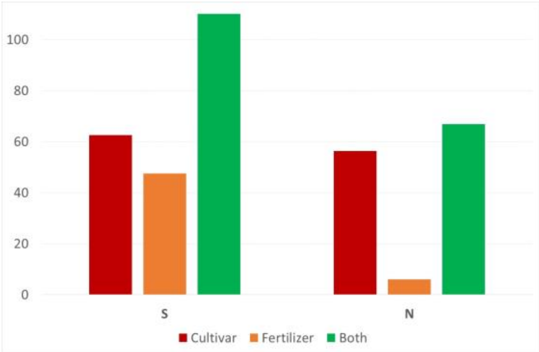
Figure 6). The analyses show that planting new trees or replacing the old ones using enhanced seed are particularly important for cocoa (Figure 6d) since the increase in productivity that can be gained from adding fertilization is minimum even in combined use with enhanced seed. For oil palm,



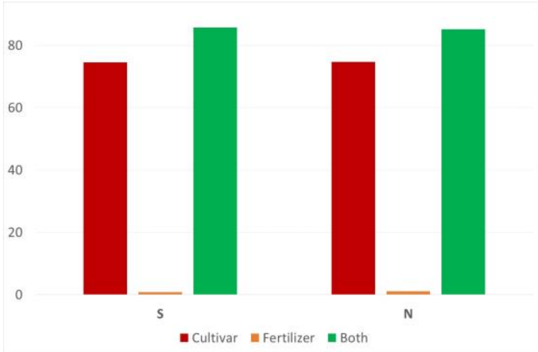
(a) Rubber



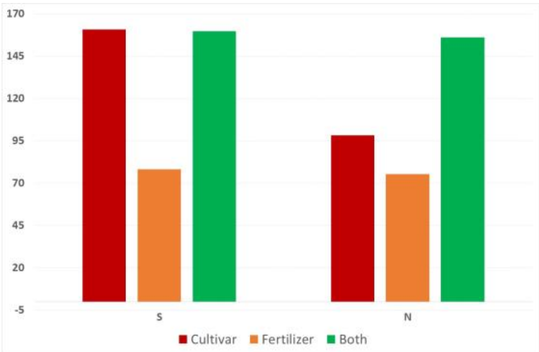
(b) Oil palm



(c) Coffee



(d) Rubber



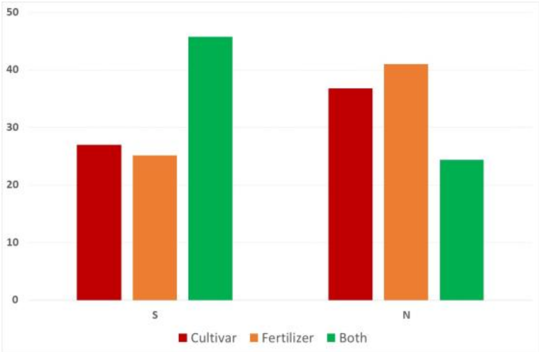
(e) Coconut

Figure 6b shows that intensification is effective mainly for plantations in non-suitable areas.

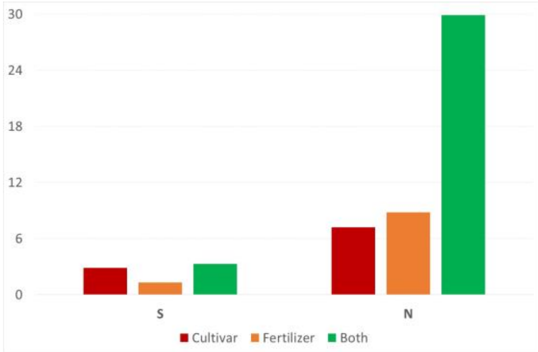
Forest sector

Modelling biophysical productivity of the forest sector is useful for examining potential economic benefit of harvesting timber or woody fibre, as well as amount of carbon that can be accumulated from forest regeneration. The latter is important in understanding the potential contribution of tree planting and natural forest regeneration to climate change mitigation especially when contrasted against the economic benefits of exploiting the area for other usage.

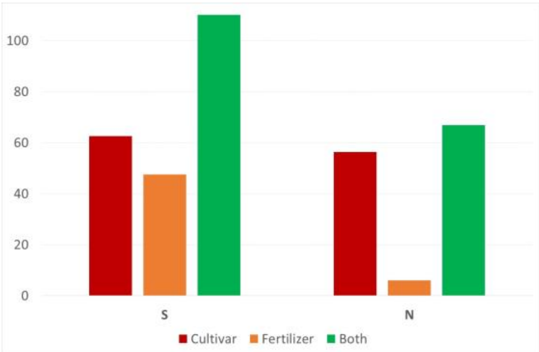
In RESTORE+, forest growth is modelled by parametrizing a dynamic net primary production (NPP) model to show how growth rates are affected by soil and climate characteristics. The NPP model is informed by MODIS NPP data (Running, Mu, and Zhao 2011) and several biophysical variables separately for different land cover and forest types. The model also utilizes AgMERRA climate datasets and HWSD for soil characteristics. Monthly water balance is also calculated based on potential evapotranspiration, actual evapotranspiration, available soil water and precipitation.



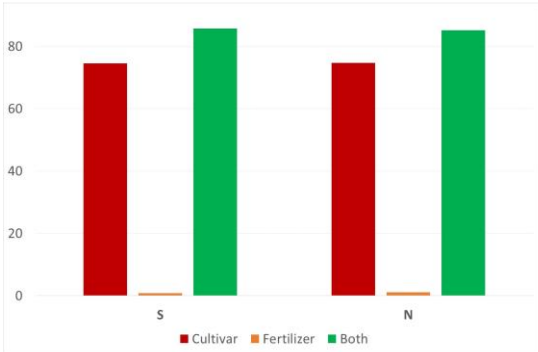
(a) Rubber



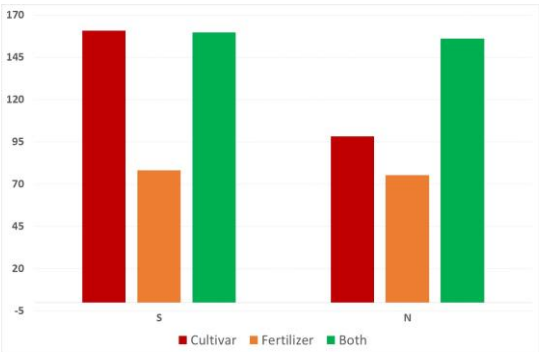
(b) Oil palm



(c) Coffee



(d) Rubber



(e) Coconut

Figure 6 Increase in productivity (%) when intensification is applied on highly suitable, moderately suitable and marginally suitable areas (S), and on currently unsuitable and permanently unsuitable areas (N). Source: RESTORE+ preliminary result

RESTORE+ models various management schemes for forest growth. The schemes represent natural regeneration and forest plantations both in dryland and peatland areas. The full extent of preliminary forest growth modelling schemes that were done to inform national scenarios are listed in Table 1 below.

Rotation time (years)	Annual increment, (tC/ha/yr)	Harvestable wood (%)	Sawn Wood (%)	Harvest losses (%)	Non woody above ground biomass (AGB) (% AGB)	Below ground biomass (BGB)/AGB (%)	Coarse woody debris (% AGB)	Litter (% AGB)
Plantations for timber *(Teak, Sengon/Paraserianthes falcataria and Mahagony/Swietenia macrophylla)*								
Teak: 20-60; Mahogany: 25-40; Paraserianthes: 5-6	Teak: 3.7-6.5; Mahogany: 6-8	teak: 63; mahogany: 58	teak: 63; mahogany: 58	teak: 37, mahogany: 42	5-6.5	teak: 22, mahogany: 18	teak: 5; mahagony:6	teak: 3-4; mahogany: 4-5
Plantations for woody fiber *(Acacia and Eucalyptus)*								
5-8	7-15	80	0	20	5-6.5	25-30	6-7	2-4
Non-assisted regeneration on dryland *(Secondary forest)*								
	4.8	#N/A	#N/A	#N/A	5-6.5	20	10	3-5
Assisted regeneration on dryland *(Secondary managed forest)*								
First thinning (50%) after 10, then every 30 years 30% harvest	5.5	50	50	50	4.5-6	20	5	3-5
Assisted regeneration on peatland 1 *(Dyera polyphylla and Coffea liberica)*								
D. polyphylla: up to 50; C. liberica: 25	D. polyphylla 6.3-10 (in case of tapped for latex 2.5-4.5); C. liberica 2.68	#N/A	#N/A	#N/A	5	25	5	5
Assisted regeneration on peatland 2 *(Shorea balangeran)*								
40 (for diameter >30 cm)	2.2-4.1	50	#N/A	#N/A	5	25	5	5
Non-assisted regeneration on mangrove *(Avicennia spp., Rhizophora spp.)*								
80	2-5				4.5-5.5	50	6.5	0

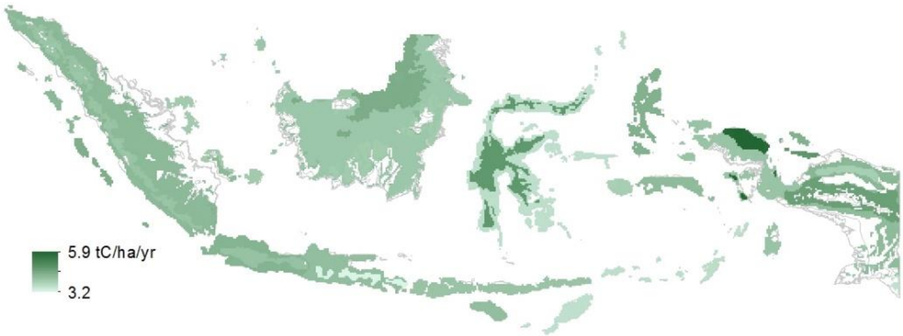
Table 1 Key management assumptions of various growth scheme. Further refinement will be conducted in modelling landscape interventions (see section 3.2.2). Source: RESTORE+ preliminary result

Forest growth modelling results in scheme specific growth curves with spatial distribution that is based on soil and climatic properties. The result can be used to investigate various questions that revolve around carbon accumulation such as economic value of harvesting timber, timing of ecological succession or arrangements around of carbon-based financing mechanism. Further, mean annual increment of the various forest growth schemes (Figure 7) can also be derived from these growth curves to allow snapshot assessment for decisions over land use competition.

(a) Plantations for timber

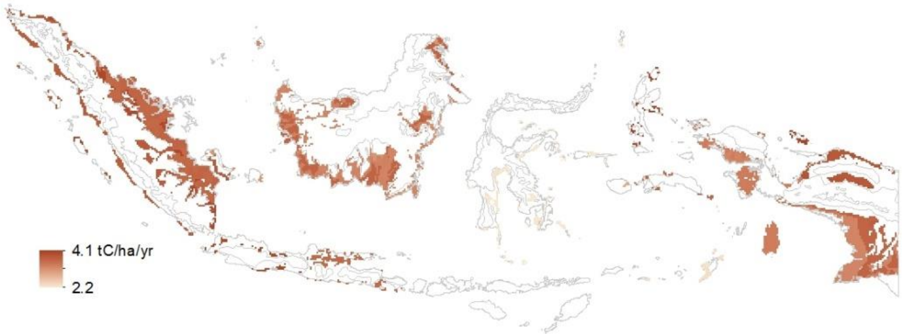
(b) Plantations for woody fiber

(c) Non-assisted regeneration on dryland (secondary forest)

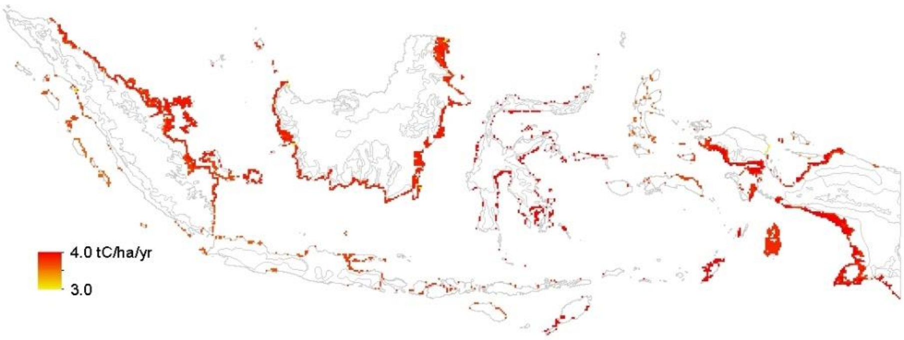


(d) Assisted regeneration on dryland (secondary managed forest)

(e) Assisted regeneration on peatland 1



(f) Assisted regeneration on peatland 2



(g) Non-assisted regeneration on mangrove

Figure 7 Mean annual increment of the various forest growth schemes (tC/ha/year). Source: RESTORE+ preliminary result

3.2.2 Modelling biophysical productivity for restoration assessment

Results from biophysical modelling described in section 3.2.1 will be further refined to allow in-depth restoration assessment during the second half of the RESTORE+ project. Following landscape interventions as grouped in the restoration 'staircase' by Chazdon et al (Figure 1), biophysical modelling will expand to cover restoration options as described in Table 2 below.

Restoration options	Detailed measures	
	in peatland	*in dryland*
(Assisted) natural regeneration	(Assisted) natural regeneration	(Assisted) natural regeneration
Planting native tree species	Belangiran (Shorea balangeran), Ramin (Gonystylus bancanus), Nyamplung (Calophyllum inophyllum), Gelam (Melaleuca leucadendra) See additional list in Table 3	Jabon (Neolamarckia cadamba), Sungkai (Peronema canescens), Mengkirai (Trema orientalis), Jabon merah (Anthocephalus macrophyllus)
Planting commercial species/commodities	**Perennials:** Jelutung rawa (Dyera polyphylla), Acacia mangium; Eucalyptus sp., Rubber, Oil palm, Sago, Pineapple **Annual crops/others:** Rice	Bamboo, Acacia mangium, Eucalyptus sp., Teak (Tectona grandis), Sengon (Paraserianthes falcataria), Mahogany (Swietenia macrophylla)
Agroforestry	**Oil palm:** Introduction of agroforestry with tree-tree system **Rubber:** Introduction of agroforestry with tree-tree system	**Oil palm:** Introduction of agroforestry with tree-tree system **Rubber:** Introduction of agroforestry with tree-tree system
Rewetting	permanent canal blocking, non-permanent canal blocking	
Land rehabilitation		Liming, terasering, erosion control (e.g. with bamboo)
Land reclamation		introducing topsoil layer + nitrogen fixating cover crops

Table 2 Restoration options to be assessed in restoration scenarios (see section 3.3.2)

Special emphasis is also given to restoration options to address peat degradation. Informed by directives from the Ministry of Environment and Forestry (MOEF), native species listed in Table 3 below will also be subject to biophysical productivity modelling.

Degraded Peat Condition	Option for Revegetation
Severely burned, drained, ex-logging activity with minimum vegetation	Jelutung rawa (Dyerapolyphylla) Perepat (Combretocarpus rotundatus) Belangiran (Shorea balangeran) Perupuk (Lophopetalum sp.) Pulai rawa (Alstonia pneumatophora) Rengas manuk (Syaygium sp.) Terentang (Campnosperma coriaceum)

Regenerate burned area, drained, ex-selective logging area, medium vegetation cover	Meranti rawa (Shorea pauciflora, Shorea tysmanniana, Shorea uliginosa) Merapat (Combretocarpus rotundatus) Durian (Durio carinatus) Ramin (Gonystylus bancanus) Punak (Tetramerista glabra) Kempas (Koompassia malaccensis) Resak (Vatica rassak) Kapur Naga (Calophyllum macrocarpum) Nyatoh (Palaquium spp.) Bintangur (Calaphyllum Hosei)
No burning, ex-selective logging, medium vegetation cover	Meranti rawa (Shorea pauciflora, Shorea tesmanniana, Shorea uliginosa) Ramin (Gonystylus bancanus) Punak (Tetramerista glabra) Balam (Palaquium rostratum) Kempas (Koompassia malaccensis) Rotan (Calamus spp) Gemor (Nothaphaebe spp., Alseodaphne spp.)

Table 3 List of native tree species for peat restoration in MOEF directives for peat restoration (Kementerian Lingkungan Hidup dan Kehutanan 2017)

3.3 Scenario assessment and land use economic modelling

Informing national stakeholder policies on how to sustainably address restoration in Indonesia requires RESTORE+ to tackle the fundamental questions of restoration as described in section 2.1. Restoration assessment should be inclusive towards varying perspectives of degradation or areas that should be subjected to restoration. The assessment should also provide information on the trade-offs between various applicable restoration options. Moreover, policy stakeholders should also be provided with information on other land use options beyond restoration to be able to make informed and implementable policies or programs.

Scenario analysis is a useful tool to address the complexity of restoration. Varying areas with restoration potential, along with a selection of applicable landscape interventions for each area, can be assigned to different scenarios. These scenarios can be then compared regarding their performances on key indicators of the stakeholders' concern. As land use decision is not limited to restoration and its various intervention options, comparing restoration scenarios with other scenarios representing alternative land uses will also be necessary. The first half of the project focused on building the main analytical tool that compiles mapping and biophysical productivity information into scenario analysis for the land use economic assessment.

3.3.1 The GLOBIOM model

According to Ricardian theory, the economic rent of a piece of land should represent, at the equilibrium, the revenues obtained from the land in its most productive use. The most profitable farming activity at any location is dependent on the local climate and biophysical context. Outside forces, such as policy and climate change may alter the relative productivity and profitability of crops in certain regions, making the conditions more favourable (unfavourable) for a given crop if, on average, climate moves closer to (further away from) the economic optimum for farmer decision of growing that crop. A land use decision model that is constructed using such an economic theory will be able to implement restoration and other land use scenarios to generate trade-off information that policy stakeholders require to inform long-term land use decisions.

The Global Biosphere Management Model (GLOBIOM) a spatially explicit partial-equilibrium (PE) model developed by IIASA. In contrast to computational general-equilibrium (CGE) models with their economy-wide structure, PE models like GLOBIOM focus on the land-based sectors with extensive description of agriculture and forestry sector in combination with a larger number of endogenous variables. The GLOBIOM model incorporates biophysical productivity estimates to better depict the relationship between land use decisions with biophysical production processes that take into account, for example, the type and quality of the soil or water availability. This type of model is able to better respect biophysical boundaries in comparison to more aggregate models that are elasticity driven.

GLOBIOM runs recursively in 10-year time steps starting in 2000 to analyse global issues concerning land-use competition between the major land-based production sectors up to 2050. The model determines optimal land and resource allocation, maximizing an objective function of consumer and producer surplus, and provides associated prices. The originality of GLOBIOM comes from representing drivers of land use change at two different geographical scales. Land related variables, such as land use change, crop cultivation, timber production and livestock numbers vary according to local conditions. Final demand, processing quantities, prices, and trade are computed at the regional level. In GLOBIOM, regional factors influence how land use is allocated at the local level, while local constraints influence the outcome of the variables defined at the regional level. This ensures full consistency across multiple scales.

Land use activities - crop, livestock, forest, and short-rotation tree plantations - and land use change are represented by a geographical grid, where land use and land use change are endogenously computed. GLOBIOM utilized potential productivity estimates from biophysical models (section 3.2) to provide insight into the potential yields, as well as the required inputs that could be derived for every individual commodity in a particular location. In determining the optimal location and combination of different agriculture and forestry activities, GLOBIOM combines biophysical productivity information with constraints such as limited land availability and consumption demand.

The food and timber demand is driven by population growth, economic growth and food diets which are taken as inputs from global scenario databases or from regional/national level data sources depending on specific research questions. However, the final demand is endogenously computed in the model according to the price level and the share of local versus imported goods to satisfy how the food demand varies according to the evolution of the relative competitiveness of each region and the transmission of prices to the producers (tariffs, transportation costs). Demand and international trade are represented at the level of the economic regions/countries based on the PE modelling approach.

3.3.2 Adjustments leading to the GLOBIOM-Indonesia model

In the first half of RESTORE+, activities were dedicated to tailoring GLOBIOM to the context of Indonesia in such a way that it can better answer questions related to long term impact and trade-offs of land use decisions to support evidence-based policy making. By explicitly addressing the interplay between the production potential, the resource constraints and the working of the markets into account, the combination of biophysical estimates with GLOBIOM will be able to answer questions around the optimal combination of activities given the limited natural resources. For example, what would be the optimal combination of land use activities in Indonesia that (1) maintains certain level of food and timber production as well as net revenues, (2) ensures food security (per capita daily calory intake), (3) generate certain trade balance of key commodities, or (4) results in certain level of forest cover and GHG emissions?

The GLOBIOM model underwent significant adjustments to transform into GLOBIOM-Indonesia to answer the above questions (Table 4). These adjustments span from the use of national datasets for model calibration to enhancements related to country specific spatial representation and temporal resolution.

	GLOBIOM	GLOBIOM-Indonesia
Economic Sector	Agriculture sector including crops, livestock and grasslands, bioenergy, and forestry	Agriculture sector including crops, livestock and grasslands, bioenergy, and forestry
Crops	Oil palm, rice, sugarcane, cassava, maize, potatoes, sweet potatoes, soybean, cotton, beans, and groundnuts	Added tree-crops that are of importance in Indonesia: coffee, cocoa, candle nut, cashew, rubber, coconut
Time Horizon	2000–2030/2050/2100 in 10-year time-steps	2000-2050 in 5-year time-steps
Geography	Global representing 30 country/regions	Indonesia singled out as a separate region from initial South East Asia region
Resolution of Production side	Bottom-up approach at detailed grid-cell level (>10,000 worldwide, at 200 km x 200 km resolution)	Enhanced spatial resolution at 50 km x 50 km
Consistent land cover-land use map	GLC-2000 harmonized with the FAO statistics.	- Land cover classes by simulation unit for 2000 based on ICRAF landcover map and large-scale oil palm plantations from Gunarso et al. and Gaveau et al. - Area and production for each product by administrative unit in 2000 based on statistics from MoA / MoF. - Land allocation by simulation unit for 2000 accounting for forest production concessions / Protected areas
Land cover classification	Primary forests, Secondary (logged) forests, plantation forests, cropland, grassland, natural land, not relevant.	Added oil palm and rubber plantations. Refinement in forest land cover classes to distinguish between pristine and secondary (disturbed) forests
Demand	Global population projection	Demand from Bappenas' IV2045 model
Post-processing		Mapping to main regions in Indonesia, improved emissions accounting

Table 4 Overview of the changes in GLOBIOM-Indonesia compared with the default GLOBIOM version

Spatial representation is conducted at the 30' grid (about 50 km in the equator), resulting in 1102 spatial units across Indonesia. All spatial input data are compiled in polygons between 5' and 30' which comprise of 5' grid cells that belong to homogeneous agroecological zones i.e. having similar soil, altitude and slope characteristics. After the data processing, these units are aggregated to uniform units of 30' grid cells.

Land cover is also adjusted using more refined and locally generated product. The FAO GLC2000 land cover map, which is used in the standard version of GLOBIOM, is replaced by the ICRAF land cover map (Ekadinata A E et al. 2011) of the year 2000. Based on the ICRAF land cover map, GLOBIOM-Indonesia classifies land cover to (1) primary (pristine) forests, (2) secondary (disturbed) forests, either managed or not, (3) plantation forests, (4) cropland (both annual and perennial crops, (5) other agricultural land, (6) grassland, (7) oil palm plantation, (8) rubber monoculture, (9) natural land and (10) not relevant land. Aggregation from the original land cover classes in ICRAF map into is described in Table 5. Distinguishing large-scale and smallholders' plantation for oil palm is achieved by using large-scale oil palm plantations dataset in Sumatra and Papua (Gunarso et al. 2013) as well as Kalimantan (Gaveau et al. 2016).

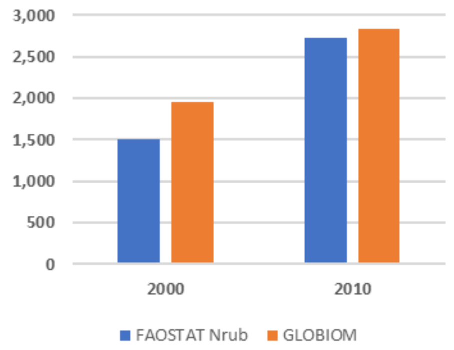
ICRAF land cover classification	GLOBIOM-Indonesia land cover classification
No Data	Not relevant
Undisturbed Forest	Primary forests
Undisturbed Swamp Forest	
Undisturbed Mangrove	
Logged Over Forest	Managed forests (secondary forests)
Logged Over Swamp Forest	
Logged over Mangrove	
Cropland	Cropland
Others Monoculture	
Grass	Grassland
Rubber Agroforest	Other agricultural land
Others Agroforest	
Rubber Monoculture	Rubber monoculture
Oil Palm Monoculture	Plantation oil palm
Teak Plantation	Plantation forests (short rotation plantations)
Pulp Plantation	
Other Forest Plantation	
Shrub	Natural Land
Other Cleared land	
Settlement	Not relevant
Waterbody	
Cloud and Shadow	

Table 5 Aggregation of ICRAF land cover classes to GLOBIOM-Indonesia land cover classes

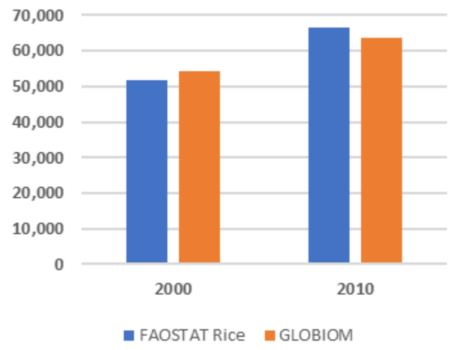
Agriculture statistics at district (or *kabupaten*) level from the Ministry of Agriculture[2] were used for calibrating production of key crops and livestock. The statistics cover 11 crops which are included by default in GLOBIOM (i.e. oil palm, rice, sugarcane, cassava, maize, potatoes, sweet potatoes, soybean, cotton, beans and groundnuts), as well as additional crops that important in the Indonesian context (i.e. coconut, rubber, cocoa, coffee, candlenut, pepper and vanilla). Four main animal types are included in GLOBIOM-Indonesia namely cattle, swine, sheep and goats and poultry. Except for areas that have been specifically mapped in ICRAF land cover map, agricultural statistics and land cover map need to be harmonized to generate cultivated area by commodity for each grid cell. This is done using the downscaling mechanism described by You and Wood (2006) using total area for each crop for each

[2] Retrieved from *Basis Data Statistik Pertanian* https://aplikasi2.pertanian.go.id/bdsp/

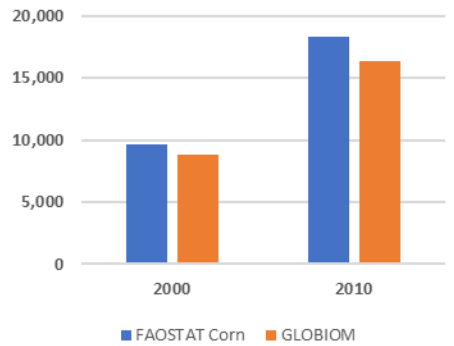
kabupaten from agriculture statistics, and the maximum cropland area in each grid cell given by ICRAF land cover map. As there is no available information on grazing area in Indonesia, pasture area is calculated by combining information on number of ruminants, grazing requirements, and forage productivity. The harmonization process allowed GLOBIOM-Indonesia to generate production of crops for the first projecting year in the model that depicts sub-national and national statistics (



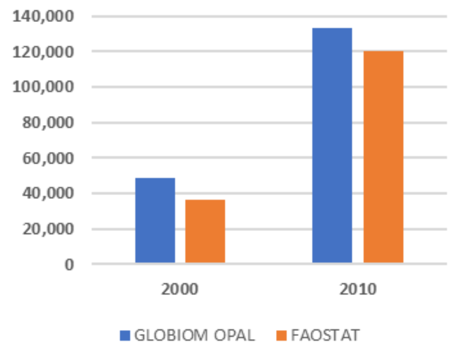
(a) Rubber



(b) Rice

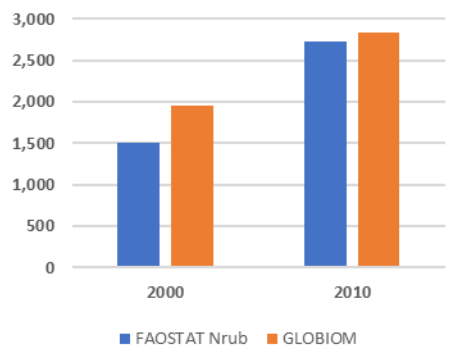


(c) Corn

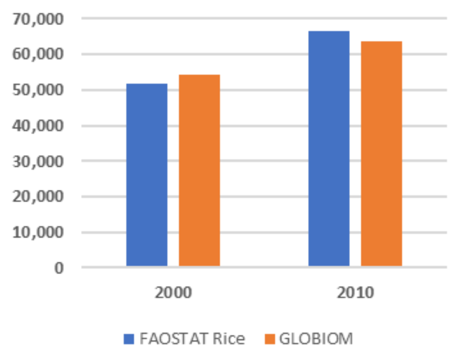


(d) Oil palm

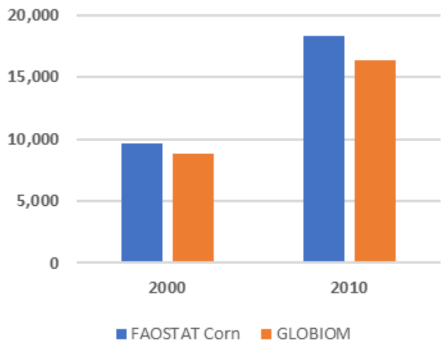
Figure 8).



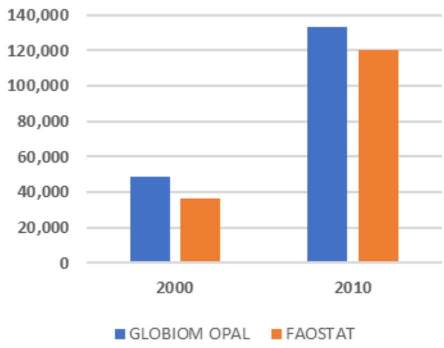
(a) Rubber



(b) Rice



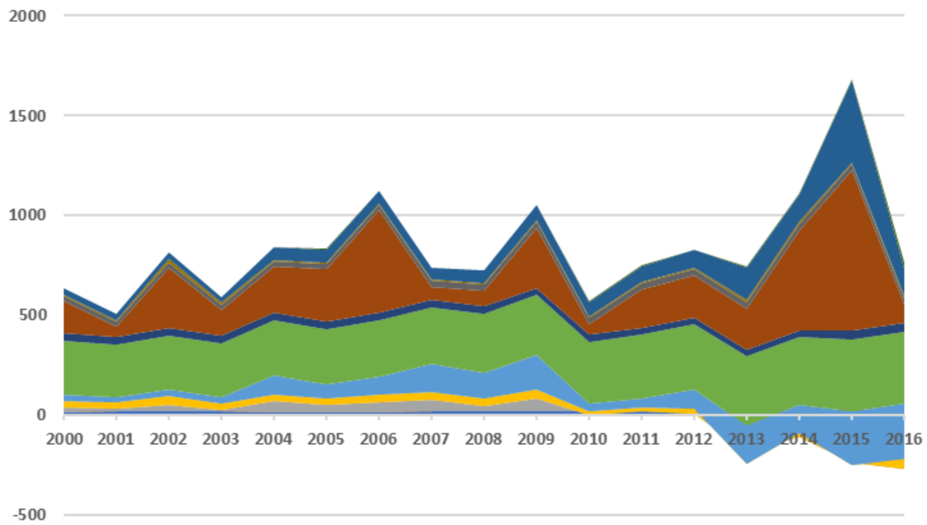
(c) Corn



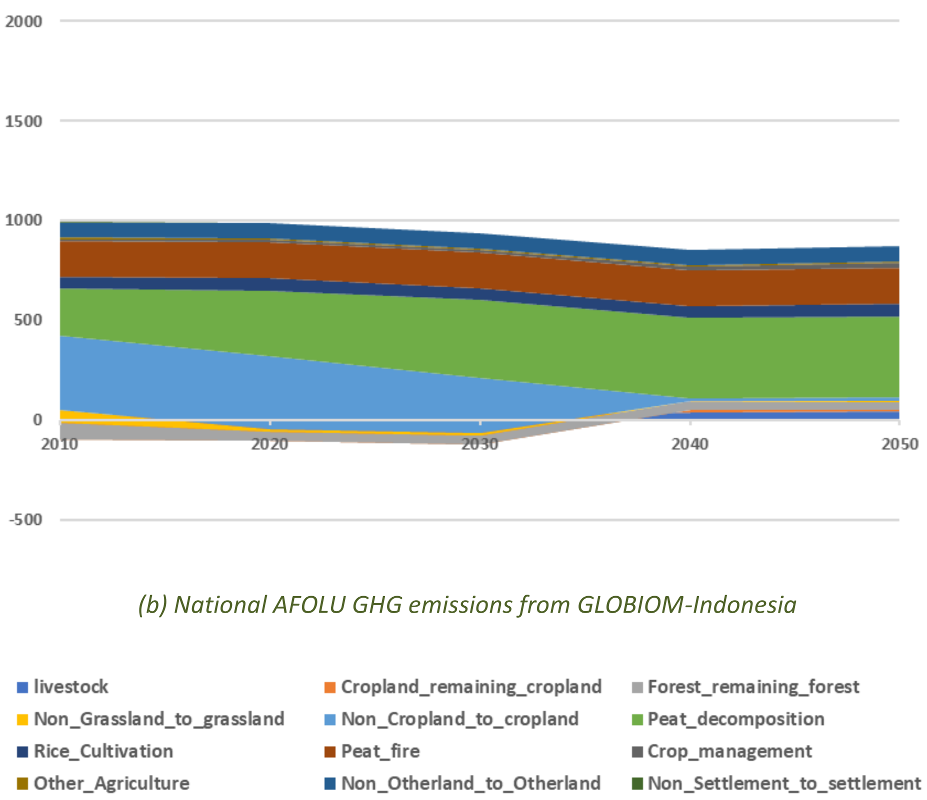
(d) Oil palm

Figure 8 Comparison between statistics (from FAOstat) and GLOBIOM-Indonesia results for production (in 1000 tons) of main agricultural crops in 2000 and 2010. Source: RESTORE+ preliminary result

The ability of GLOBIOM-Indonesia model to depict land use activities should also be reflected in **greenhouse gasses (GHG) emissions** as an important parameter. The model utilizes carbon contents of the different land cover classes to calculate GHG emissions. Below and above ground biomass that are used to calculate carbon stock are directly coming from estimates of the forestry growth modelling (Forest Sector in section 3.2.1). For peat emissions, drainage of peat soils leading to their decomposition is also considered. Peatland map is used to calculate the share of each land use class in peatland for each simulation unit. The hectares of forest or other natural land conversion towards a land cover with productive use are multiplied by the share of peatland in that location. Because peatland continues to emit GHG, the hectares of peatland conversion are cumulated over the years.



(a) National AFOLU GHG emissions from 2nd BUR of Indonesia



(b) National AFOLU GHG emissions from GLOBIOM-Indonesia

Figure 9 GLOBIOM-Indonesia emissions (in MtCO2 equivalent) compared against the 2nd BUR of Indonesia. Source: RESTORE+ preliminary result

Carbon sequestration from tree growth is considered for the main tree-crop plantations such as oil palm, cocoa, coffee, coconut, and rubber. The values utilize estimates of the WaNuLCAS model (Perennial Crops in section 3.2.1). For calculation of below-ground biomass, the IPCC below to above-ground biomass ration of 0.2 (subtropical humid forest; above biomass lower to 125 ton dry matter per hectare) was utilized leading to a total carbon biomass of 48 tons. GHG emissions results of GLOBIOM-Indonesia can be compared against the Biennial Update Report (BUR) to the UNFCCC (Government of Indonesia 2018). While the emissions are on the same order or magnitude, one of the largest sources of the emissions over the past years have been peatland fires, which can only be exogenously introduced in the model (Figure 9).

Additionally, the most recent adjustment to GLOBIOM-Indonesia include increasing the temporal resolution so the model runs at 5-year timesteps instead of the 10-year timestep of the standard version. The model can also incorporate infrastructure network information to better depict transportation costs of each grid cell. Being a PE model, GLOBIOM-Indonesia can complement other models by using exogenous assumptions from these models (e.g. GDP growth, population growth, dietary changes) or providing land use sector information as input to these models.

3.3.3 National scenarios to support the LCDI

The role of competing land uses in the decline of Indonesia's natural forest cover has been extensively discussed. Commitments to reduce GHG emissions by 26% by 2020, together with a moratorium on activities in primary forests and peatlands helped strengthen the countries' environmental goals.

Simultaneously, Indonesia experiences significant economic growth based on natural resources and growing demand for some of its key products. Future impacts of these economic pressures on land cover and the environment remain largely unknown. Adjustments that led to GLOBIOM-Indonesia were made in the effort to provide quantitative knowledge on questions within this topic. An initial step to such an effort took form in the interaction between RESTORE+ and the LCDI initiative.

Within LCDI, GLOBIOM-Indonesia interacted with the IV2045 model and SpaDyn model initiated by Bappenas. IV2045 is a system dynamics model that integrates a set of feedback structures for the macroeconomy, society, and a representation of natural capital including energy, land, water resources, biodiversity and carbon emission systems in Indonesia (Kementerian PPN/Bappenas 2019). The IV2045 model enables a coherent, comprehensive appraisal of social, economic, and environmental policies, including low carbon policies. IV2045 gains spatial insight from SpaDyn and GLOBIOM-Indonesia which work in synergy. SpaDyn model utilizes cellular automata inspired approach to project future land cover changes based on existing land cover status combined with land suitability and road availability. The model also projects changes in mining land and urbanization to cover possible land cover classes more exhaustively. Such an insight complements projections of the agriculture and forestry sector from GLOBIOM-Indonesia that take into account interactions and constraints from biophysical realities.

To inform various assumptions and parametrizations of multiple national LCDI scenarios in IV2045, several national land use scenarios were developed using GLOBIOM-Indonesia to evaluate both independent and collective impacts of key land use interventions. A combination of these interventions forms the land use sector policy which is then combined with other sectoral policies (e.g. energy, water, and fishery) to represent varying levels of Indonesia's potential low carbon ambitions. Enhancing agriculture productivity, land designation policy enforcement and restoration were identified as three main areas of land use intervention that emerged from LCDI interaction with RESTORE+. These three areas of interventions were then translated into five scenarios in GLOBIOM-Indonesia (Figure 10).

The first scenario is (NoCC) is an extrapolation of existing land use patterns which represents the baseline situation. The following scenario is a *conservation* scenario (CONS) where alignment between land designation and actual land use is expected to take place. Such an intervention depicts a hypothetical situation where Indonesia was able to achieve full enforcement of its conservation areas. The approach is of course a rather limited understanding of conservation since it relies on legal designation instead of ecological considerations. Nevertheless, such a scenario may still contribute significantly to ecological conservation since legal designation is often compromised in reality due to pressure from land demand, mainly for agriculture activities.

Enhancing agriculture productivity, in output per hectare, is widely discussed as a potential solution as it is expected to still enhance economic activities while maintaining reasonable levels of production areas. To investigate such a hypothesis, an intensification scenario (INTENS) was developed in GLOBIOM-Indonesia using intensified productivity information from both EPIC and WaNuLCAS model (section 3.2.1). GLOBIOM-Indonesia further examined the impact of implementing conservation and intensification measures simultaneously in CONS_INT scenario. Finally, a fifth scenario (RESTORE) was developed to combine multiple land use interventions that corresponds with the most ambitious LCDI scenario. In RESTOR scenario, conservation and intensification measures are further strengthened with peat restoration and non-assisted restoration in primary forest areas that experienced disturbance or land conversion from 2010 onwards. The restoration intervention in this scenario represents a simplification to the longer-term project goal of a holistic and inclusive restoration assessment. The decision for this simplification is motivated by the plan to use the initial stages of the project to build analytical foundations for in-depth restoration assessment, while still allowing contribution to the LCDI modelling process.

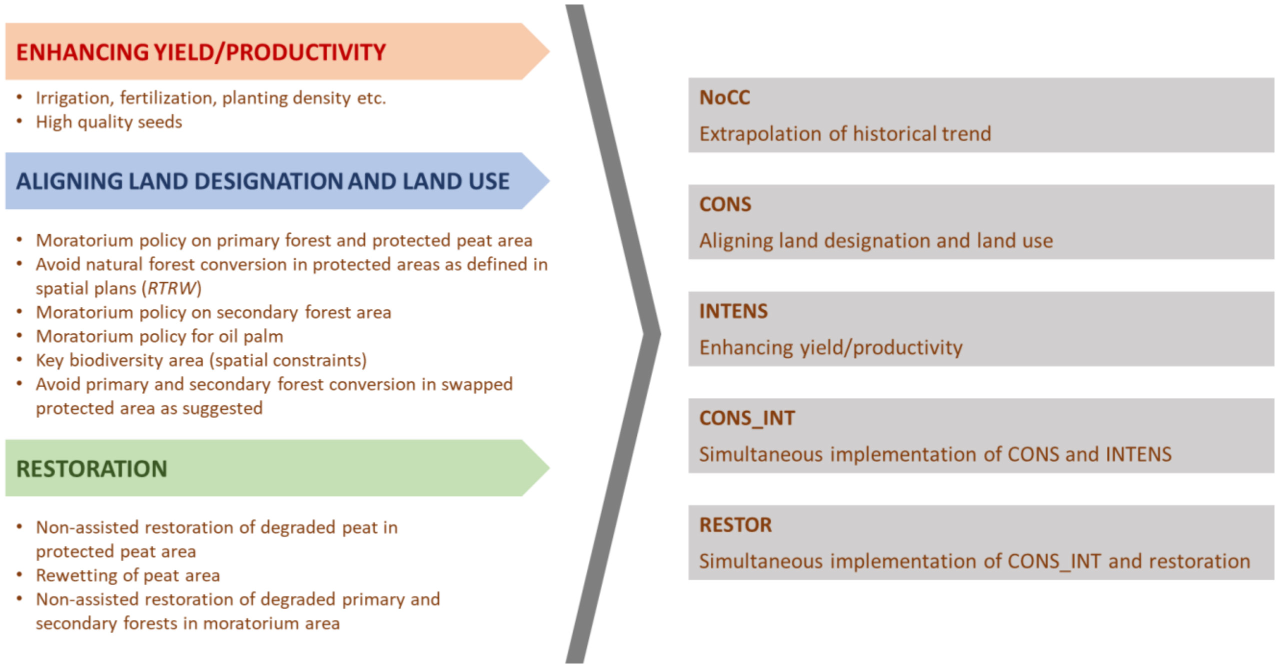


Figure 10 Scenario design for GLOBIOM-Indonesia interaction with LCDI modelling efforts.

Compared to the baseline scenario, other scenarios have indeed resulted in higher areas of natural forest cover (Figure 11). The reduction in natural forest cover losses ranged between 30-50% in all alternative scenarios compared to the loss in the baseline scenario. Independent implementation of land use and designation alignment generates similar amount of forest cover loss when compared to the scenario of intensified agriculture productivity.

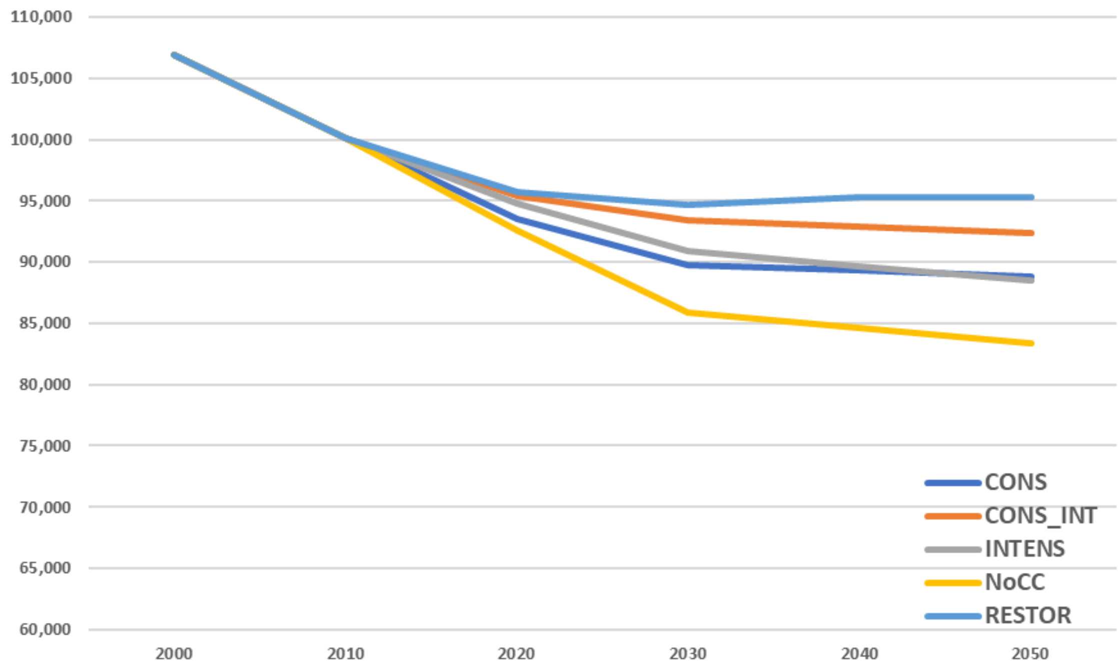
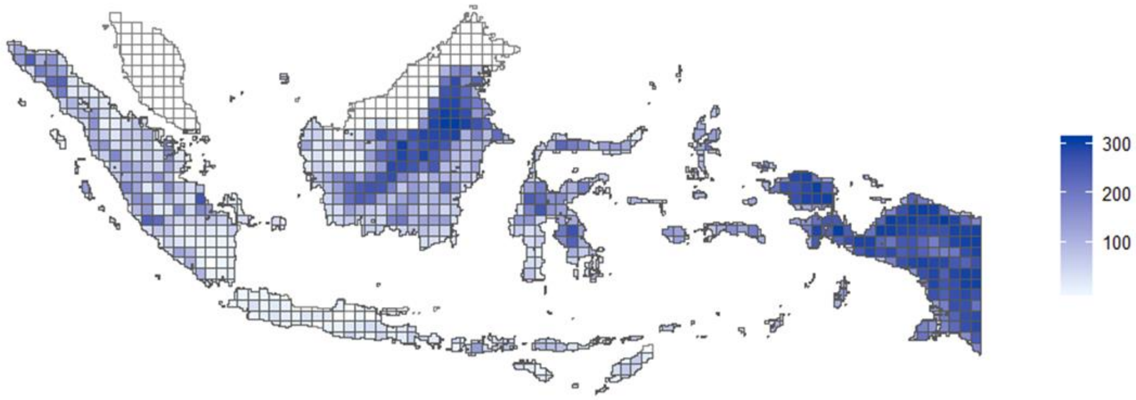


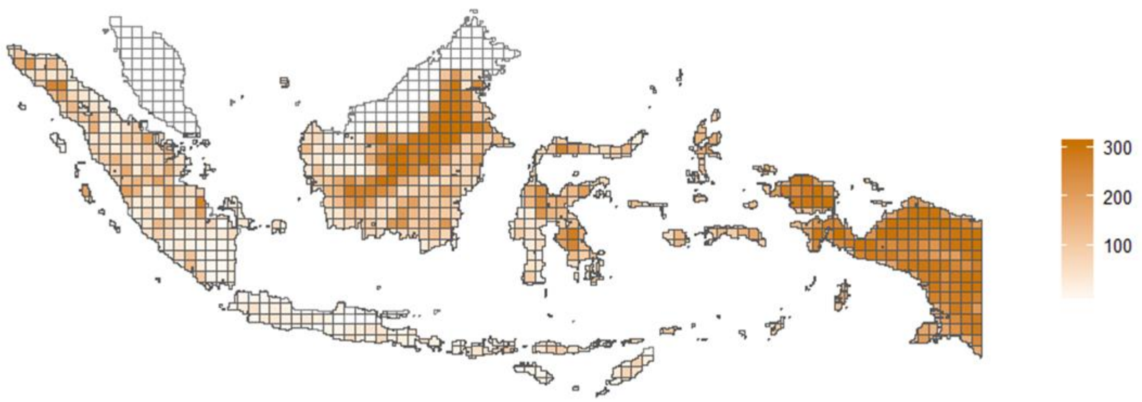
Figure 11 Total area of natural forest cover (in 1000 ha) from five GLOBIOM-Indonesia scenarios. Source: RESTORE+ preliminary result

The aggregated land cover dynamics that GLOBIOM-Indonesia generate can be analysed further due to its spatially explicit nature.

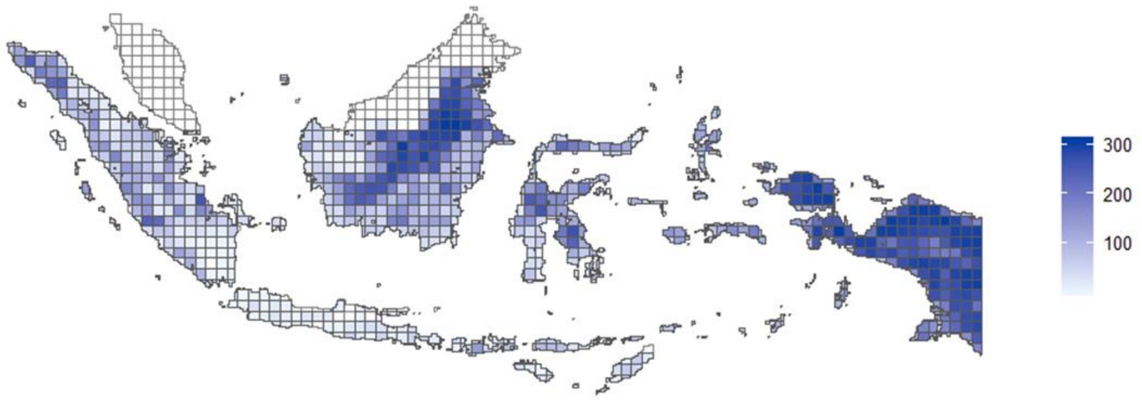


(b) Restoration scenario (RESTOR)

Figure 12 indicates the discrepancy in spatial distribution of forest cover intensity between baseline and RESTOR scenarios. Despite similar overall spatial distribution, varying intensity can still be observed in several locations.



(a) Baseline scenario (NoCC)



(b) Restoration scenario (RESTOR)

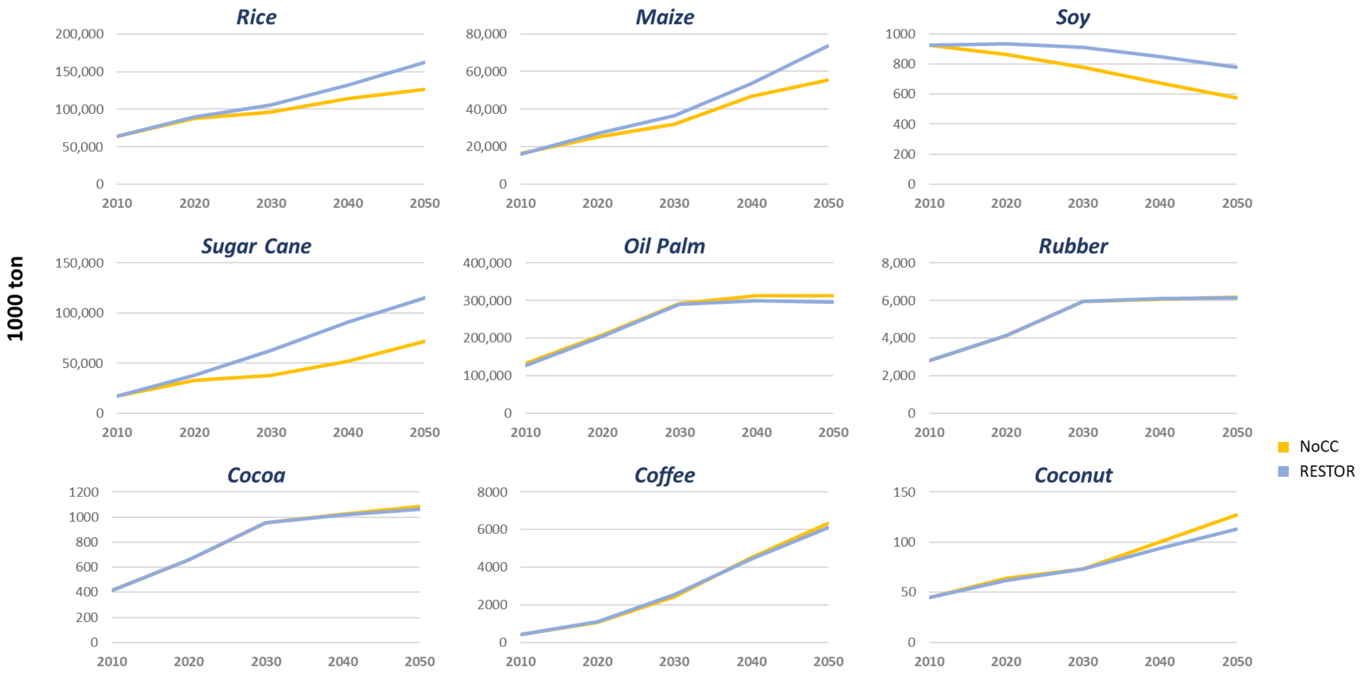
Figure 12 Spatial distribution of natural forest cover loss from GLOBIOM-Indonesia. Source: RESTORE+ preliminary result

Along with land cover dynamics, GLOBIOM-Indonesia also generates detailed information on production and area of key crops (). Such an approach addresses the need for systemic analysis in examining important land use policy questions (e.g. intensification) which are highly related with other uncertain factors such as future demands. LCDI interaction with Bappenas also led to collaboration with the Food and Agriculture Directorate within the ministry to investigate the feasibility of yield improvement for key food crops (**Error! Reference source not found.**).

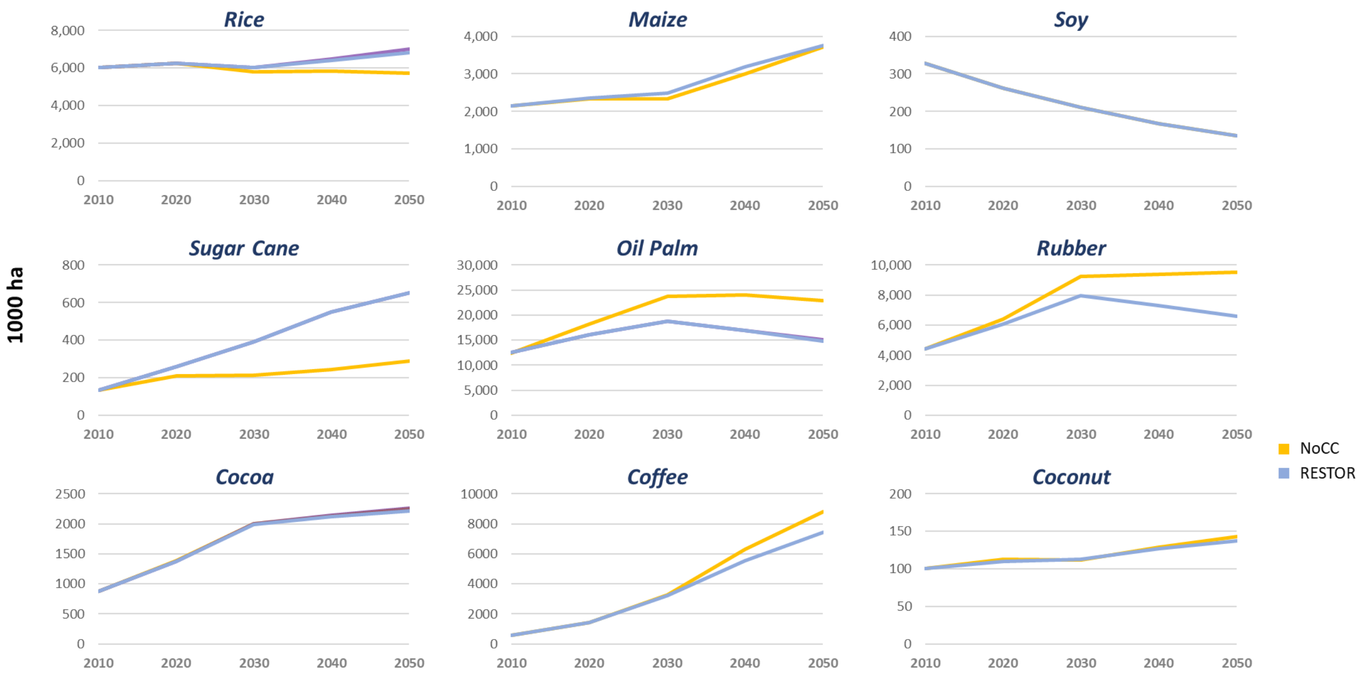
Box 2 Improving the yield of key agriculture commodities

Discussions over GLOBIOM-Indonesia results for main agriculture crops in Indonesia led to the question of actual feasibility of enhancing productivity of these crops. The question extends beyond the scope of variables and considerations of the model as it also relates to other issues such as seedling availability, farmers' preference, as well as risks for disturbances from pests and diseases. Bappenas Food and Agriculture Directorate facilitated experts from main research and development facilities on key crops to provide feasible intensification assumptions to the model.

For **cocoa**, representative from Indonesia Coffee and Cocoa Research Institute (ICCRI) pointed that intensification can be feasible for premium commodities enjoying better prices. Cocoa intensification is still limited to national seedling production capacity which is currently ~8 million seeds/year. For **rubber**, management practices play a significant role in identification intensification opportunity. Representative from Sembawa Rubber Research Center indicated that seeds used smallholders' rubber plantation are not responsive to enhanced input. Therefore, intensification effort for smallholder's plantation ideally focuses on replanting while implementation of good agricultural practices is key for industrial plantations. Similar situation also applies for **oil palm** where replanting is a key intensification measure for smallholders' plantation. However, according to representative from Indonesian Oil Palm Research Institute (IOPRI) replanting is also highly constrained with price fluctuation leading to limited rate of commercial replanting. Finally, representative from the Indonesian Center for Food Crops Research and Development suggested increasing cropping index through better irrigation as the main measure in improving **rice** productivity.



(a) Production



(a) Area

Figure 13 Production (in 1000 tons) and area (in 1000 ha) of key agriculture commodities in GLOBIOM-Indonesia. Source: RESTORE+ preliminary result

3.4 Biodiversity assessment of restoration

RESTORE+ seeks to understand the biodiversity implications of choosing between different policy options for large-scale landscape restoration. Therefore, the aim is to estimate biodiversity values in degraded/marginal areas building on biodiversity databases, enhanced by crowdsourcing and big data analysis. These are then coupled with land use models to assess implications of policies applying alternative definitions of degraded land. To meet this challenge, state-of-the-art biodiversity assessment methodologies are being deployed.

Through the use of biophysical and GLOBIOM modelling in Indonesia, spatially-explicit projections of land use change are generated for each restoration scenario under consideration (see chapter 3.3.1 for more details). These land use change maps and associated data on crop and livestock production, are the starting point for the biodiversity assessments. Land use change is one of the major causes of biodiversity change globally, particularly through its impact on availability and distribution of habitat for plant and animal species. However, the intensity of land use is also relevant, for example when industrialization of agricultural operations increases pollution and nitrification of soils and freshwater resources.

The two biodiversity assessment methodologies employed here, take into account both aspects of land use change impacts on biodiversity, focussing on (1) species habitat change and (2) biodiversity intactness. Species habitat change looks at the change in the contribution of each grid cell to the distributions of mammals, amphibians and birds. For each modelled species, it uses the IUCN Red List data on the species' range and also habitat affiliation – cross-walked to the GLOBIOM land cover classes – to calculate change in extent of potentially suitable habitat, cell-by-cell, according to each restoration scenario. These changes are aggregated at the cell level to create a combined score of species habitat change. In doing so, the relative rarity of each species is considered, giving greater weight when species lose not just a large area, but a large proportion, or their available habitat.

The biodiversity intactness methodology, developed in collaboration with the Natural History Museum London, is based on the PREDICTS database (PREDICTS - Projecting Responses of Ecological Diversity In Changing Terrestrial Systems) of control-impact comparisons, containing 4 million data points for over 52,000 species across all major taxonomic groups. The statistical comparison of site-level species community abundance/diversity, land use and other anthropogenic pressures on biodiversity such as human population density and infrastructure, allows for a wall-to-wall prediction of biodiversity intactness relative to a pristine baseline for anywhere in the world.

Finally, habitat configuration, as is effects organism dispersal and genetic exchange, is also a critically important factor for biodiversity, especially under climate change scenarios. This aspect is therefore planned to be incorporated into the biodiversity impact modelling. For Indonesia the approach trialled calculates a probability of connectivity score for any grid cell within a landscape, based on the contribution to overall landscape connectivity or intactness that it would make if restored to quality biodiversity habitat. This has been applied to a region of South Sumatra where burned or logged-over peat swamp forest areas can be prioritized based on this criterion.

Further, new site-level biodiversity data in Indonesia (and South East Asia more broadly) were sourced to improve the biodiversity impact modelling. A literature review on the biodiversity values of different biomes in Indonesia including degraded lands was undertaken and a summary of international commitments and land-use policy options relevant to degraded lands and different interpretations of the concept within policy was produced.

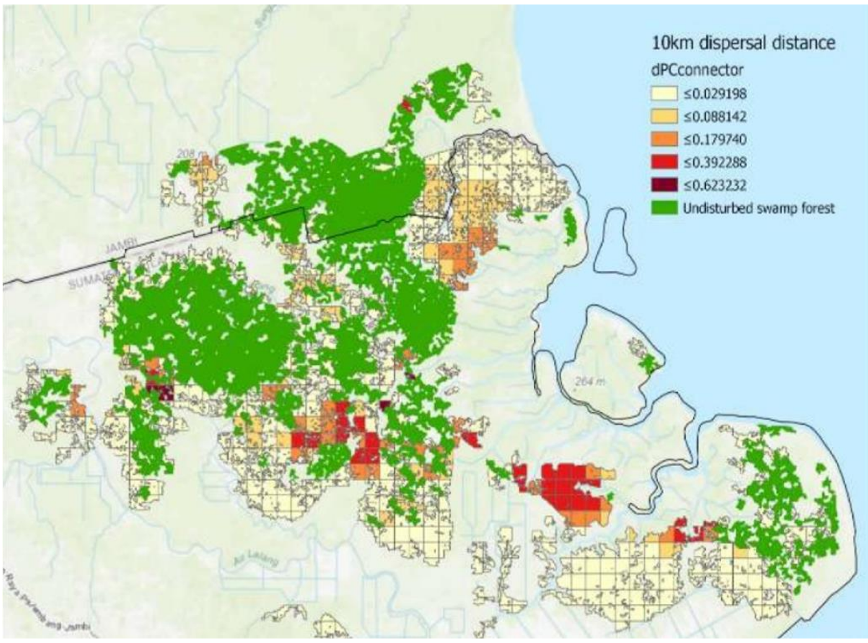


Figure 14 High (red) and low (pale) probability of connectivity of degraded peat swamp areas (10 km grid cells) in South Sumatra. Green areas show intact peat swamp habitat. Source: RESTORE+ preliminary result

Figure 14 High (red) and low (pale) probability of connectivity of degraded peat swamp areas (10 km grid cells) in South Sumatra. Green areas show intact peat swamp habitat. Source: shows the connectivity modelling undertaken for peat swamp forests in a region of South Sumatra. Here, degraded peat swamp areas are shown as 10 km grid cells, which are scored depending on the contribution to the connectivity of the peat landscape they would make if they are restored, with greater contributions indicated by red and deep orange colors. This particular run is based a hypothetical focal species with a mean dispersal of 10 km, which can be varied. The application of weightings highlighting areas holding proportionally more unique biodiversity (based on the range rarity of Red List species) and more recent conversion of the habitat (with potentially less cost of restoration or higher rate of success) was tested.

After this first application, refinements are being made to the biodiversity models based on feedback received at the RESTORE+ mid-term meeting. The models will be shortly tested on the first outputs of GLOBIOM-Indonesia. Further work will be carried out on integrating the climate change dimension, and on applying connectivity modelling methods across both countries. It is further planned to refine the models to better take into account the temporal nature of biodiversity recovery during and following ecosystem restoration.

3.5 Studies on relevant policies

By examining the implication of social forestry schemes and land use impacts of palm oil production in Indonesia, RESTORE+ addresses two relevant policy areas that can have a significant impact on degradation and restoration efforts. Understanding the consequences of these policies is therefore an important component in achieving effective and sustainable results.

3.5.1 Investigating early effects of Social Forestry

Land governance shortcomings remain a major challenge for curbing deforestation in Indonesia. Therefore, *Social Forestry Permits* (SFP; see Figure 15) offer a compelling approach to protect forests in Indonesia: if capable communities are incentivized to protect their forests, with state guidance, then deforestation should decrease, while forest conditions should improve (Liu and Bona 2019). Whether this is empirically valid remains an open question that is addressed by the RESTORE+ project.

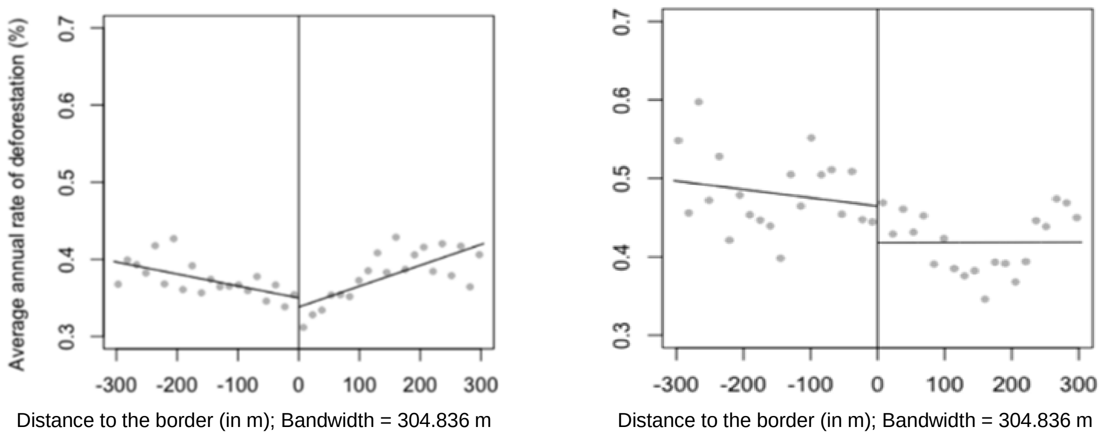
Scheme	*Rights granted to community*	*Objectives*
Community forest *Hutan Kemasyarakatan - HKm*	• Use and management of non-timber forest products (NTFPs) in protection forest zones • Use and management of timber in production forest zones (with additional permit)	• Community empowerment • Rehabilitation of state forest
Village forest *Hutan Desa - HD*	• Use and management of NTFPs and forest ecosystem services	• Improvement in village welfare • Protection of state forest
Community plantation *Hutan Tanaman Rakyat - HTR*	• Use and management of timber in production forest zones	• Higher quality production forests • Improve community welfare
Partnership *Kemitraan*	• Collaboration with a state-owned or private company • Use of NTFPs	• Benefit sharing between communities and companies

Figure 15 Social forestry schemes and objectives. Source: Liu and Bona 2019

The method applied to this end relied on comparing deforestation rates in protection forest areas managed with social forestry area (mainly so-called village forests, *hutan desa*) to state-managed protection forest areas. Trees or observations assigned to an SFP area qualified as the treatment group, while those in state-managed forest areas qualified as the control group. A regression discontinuity design was applied with the border between administrative boundaries serving as the cut-off point. Any jumps in outcomes after the introduction of a social forestry permit at or near the border could then be attributed to the treatment.

The results shown in Figure 16 indicate that social forestry permits in Indonesia have led to small but measurable reductions in deforestation rates. However, looking more deeply into the regions reveals that there are important heterogeneities between provinces, which call for further investigation. Next steps will therefore investigate increases in land cover, i.e. into the restoration and agroforestry part of Indonesian forestry regulation, to add to the insights that have been gained on forest protection.

In particular, a focus on socio-economic outcomes would be helpful to link the impact of this regulation to the wider Indonesian policy agenda.



(a) Pre-Treatment/SFP Plots

(b) Post-Treatment/SFP Plots

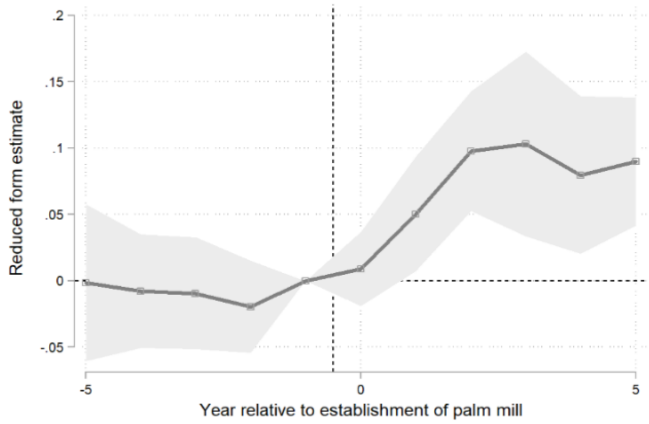
Figure 16 Comparison of annual deforestation rate at the border (0 on the x-axis) between a village forest (hutan desa) area and state forest, both in protection areas. Figure (a) shows the difference before the introduction of the SFP/pre-treatment and (b) shows the difference after the introduction of the permit/post-treatment. Source: Kraus et al. 2020 in production

3.5.2 Investigating entry points to reduce adverse land use impacts of palm oil production

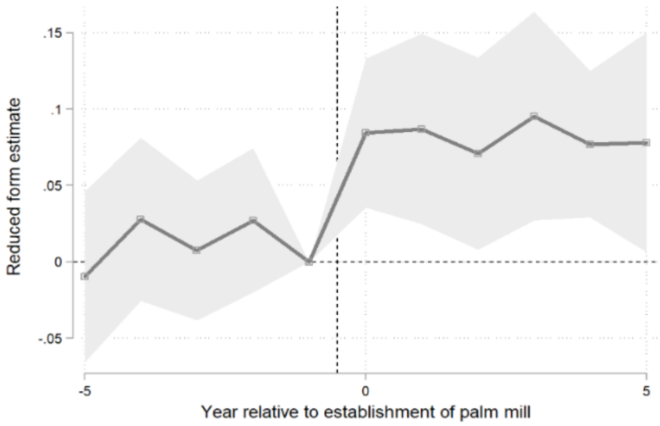
Palm oil and firm productivity

The effect of palm oil mills and plantation on the productivity of the remainder of the industrial sector is being investigated. A naïve look at the data indicates that palm oil activities might 'crowd out' industrial development, since factories in palm oil areas develop less well than factories in the rest of the country, for example in Java or in more urban areas of Sumatra and Kalimantan (Kraus et al. 2020 in production). But, since areas with palm oil are different from other areas, e.g. in terms of their infrastructure or socio-economic trends, econometric techniques are used to build more suitable control groups and tease out the dynamic effect of the establishment of an oil palm mill on factories from other industries in the same district. First results show that over the first five years there is an increase (see Figure 17**Error! Reference source not found.**). This contradicts the theory of a crowding out of non palm oil activities, at least in the shortrun, but is in line with the literature on the local effects of resource windfalls or agglomeration spillovers from new factories, e.g. due to transportation infrastructure.

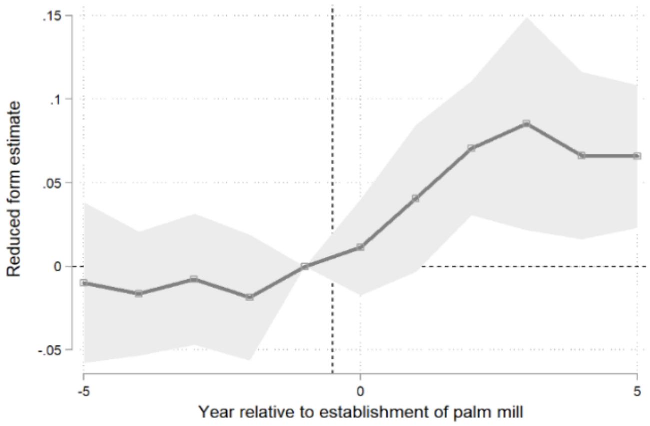
The study uses data on all factories in Indonesia and new data on the establishment of mills, the *universal mill list*. Previous studies have worked with the location of mills, but couldn't manage to trace factory performance over time. Intuitively panel regression analyses make comparisons between *treated* factories (i.e. a palm mill is established in their respective districts) and *control* factories that are previously treated, later treated or not treated at all. The most important assumption in such regressions is that treated units would have evolved on the same trend as those (even if they are not exactly the same). Since already treated units act as control units, it is likely that control groups are on different trends than treatment groups. A so called stacked design is being used that separates each treatment event out and constructs a valid control group for it. Since districts are treated repeatedly (i.e. several mills are established over time), factories appear several time in the treatment group. Intuitively the regression analysis generates the average effect over all these individual events.



(a) Sales (log)



(b) Total Factor Productivity (log)



(c) Labour productivity (log)

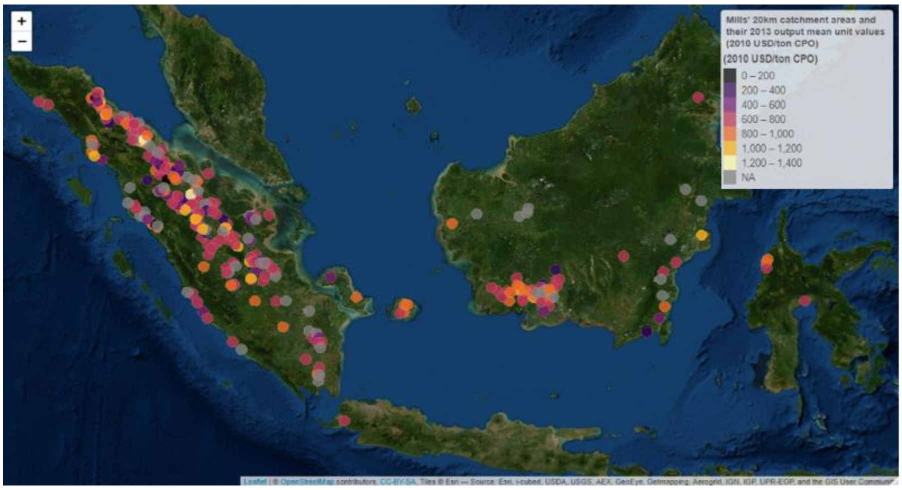
Figure 17 Non-palm oil factory performance in (a) sales, (b) total factor productivity and (c) labour productivity 5 years before and 5 years after establishment of palm mill in the same district. Source: Kraus et al. 2020 in production

Impacts of palm mills on Indonesian land use

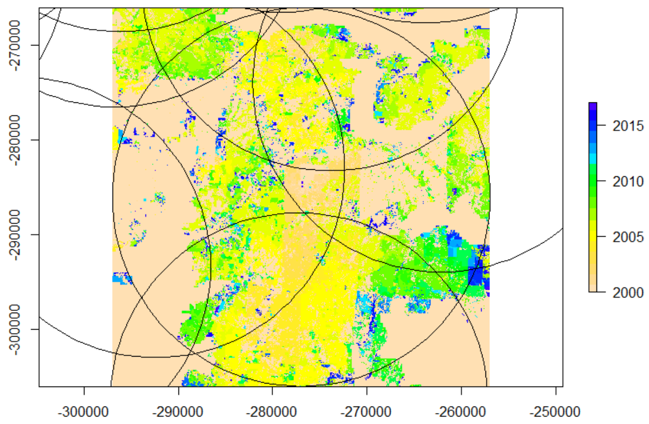
A dataset on individual palm oil mills (exact location, production, inputs prices, output prices, productivity, wages, ownership) was assembled to investigate entry points to reduce negative land use impacts, based on palm mill characteristics. In particular, the price elasticity of forest conversion to oil palm plantations will be identified. This will help informing on the efficiency of market-based instruments for conservation purposes. The identification will rely on spatial and temporal variations in the average unit values plantation managers can expect to get for their products from reachable mills. Figure 18 shows the annual forest conversion to oil palm plantations (Figure 18 c) and mills within 20km catchment areas in 2003 (Figure 18 a) and 2013 (Figure 18 b) respectively.

The upcoming analyses will investigate palm mills' heterogeneous impacts on land cover and their reaction to certain policy changes, including export taxes, investment rules and the introduction of certification.

(a) Mills' 20km catchment areas and their 2003 output mean unit values (2010 U$D/ton CPO)



(b) Mills' 20km catchment areas and their 2013 output mean unit values (2010 U$D/ton CPO)



(c) Annual forest conversion to oil palm plantations from 2000-2015

Figure 18 Annual forest conversion to oil palm plantations and mills 20km catchment areas. Source: Kraus et al. 2020 in production

4. RESTORE+ in Brazil

In Brazil, the RESTORE+ project focuses on tropical forest degradation and utilizes big data analysis methods to generate yearly country map datasets for the period 2000-2020. A national assessment examines the implications of using different definitions of degraded land on production, biodiversity and wider land use in Brazil, and national scenarios of restoration and sustainable food/energy crop production on degraded lands. For this technical assessment, the GLOBIOM-Brazil model is utilized to explore different scenarios, and generate associated maps, datasets and reports that will inform policy makers and other stakeholders in Brazil. Specifically, the assessment covers:

1. technical recommendations on the definition of the legal framework that will regulate the environmental reserve quotas market which is foreseen in Brazil's Forest Code;
2. technical recommendations on the formulation of Brazil's national policies for forest protection (including Amazon Region Protected Areas (ARPA)) and forest restoration considering the Forest Code (including Rural Environmental Cadastre) and international REDD+ arrangements to which Brazil has agreed to take part; and
3. identification of the target areas for forest restoration in Brazil, considering socio-economic costs and benefits, biophysical constraints, and national environmental policies for forest regrowth after deforestation and degradation, to support Brazil's contribution to the Bonn challenge.

Datasets from the technical assessment will be disseminated to the wider public through a web-based analytical and visualisation tool which will also be useful for national and local planners in Brazil.

The activities of mapping degradation and potential area for restoration by assessing satellite image time series with machine learning to define Land Cover/Use maps (SITS methodology) (chapter 4.1) as well as the approach to analyse the *Legal Reserve* (LR) requirements together with the *Rural Environmental Cadastre* (CAR) to define legal reserve deficits and assess potential areas for restoration (chapter 4.2) are conducted by the RESTORE+ consortium partner INPE. They also lead the assessment of land use dynamics and climate change impacts on land use dynamics (chapter 4.3) as well as the land use and restoration policy assessment (chapter 4.4). As in Indonesia, UNEP-WCMC works on restoration and biodiversity in Brazil (chapter 4.5). EDF and LSEE are responsible for the restoration and opportunity cost analysis (chapter 4.6).

4.1 Mapping land use and land cover using SITS analysis

Satellite image time series and in-situ sampling are analysed by applying a machine learning approach to define land cover and land use maps. To produce these maps of Cerrado and Amazon biomes, a variety of steps that demand different analysis methods were conducted and supported by a newly developed open source software called *sits*.

These land use and cover maps showed reasonable accuracy for modelling purposes. The results enable an informed assessment of the interplay between production and protection in the Brazilian

Amazon and Cerrado biomes, being relevant to support land use and cover planning and public policies, such as the calculation of greenhouse gas emissions for the implementation of Brazil's NDCs. Additionally, they are temporally consistent and provide information on deforestation and changes in natural vegetation and on agricultural expansion and productivity increase. *Sits* maps also have specific advantages for the RESTORE+ modelling activities, mainly for GLOBIOM-Brazil, as *sits* identifies crop types, especially double cropping areas, which are consistently expanding in Brazil. They are available for the years 2000 to 2016[3] and will be updated as new data is collected and made available. As next steps, small adjustments to this innovative methodology to generate land use and land cover maps will be applied. For example, future efforts will be made to produce new collections for the other remaining Brazilian biomes.

Along the development of this activity, considerable effort was also made to develop the family of software packages to cover the whole process for creating land use and cover maps, which are *sits*, *WTSS*, *EOCubes*, *lucCalculus*, and *sits.validate*. These packages can be found in the e-Sensing's GitHub repository at https://github.com/e-sensing. They can also be useful to other researchers interested in building and analysing land use and cover maps for any country or region of the globe.

4.2 Mapping degradation and potential area for restoration using CAR analysis

For the second approach applied in Brazil to assess potential areas for restoration, *Legal Reserve* (LR)[4] requirements are analysed by using information from the Rural Environmental Registry (in Portuguese *Cadastro Ambiental Rural*, or CAR). CAR was implemented with the latest version of the Brazilian Forest Code (Law 12.651/12) from 2012, setting up general rules for those illegally deforesting their LR areas. The Environmental Regularization Program (in Portuguese *Programa de Regularização Ambiental*, or PRA) allows their regularization if they restore their LR and declare the location of their properties in the CAR system.

Computing deficits and surpluses of these LR areas is an important step to study restoration scenarios in Brazil. However, the data available to estimate such debits or surpluses have great uncertainty. The objective was therefore to combine CAR with the best data currently available to estimate scenarios of deficits and surpluses of LR in Brazil, according to the Forest Code. The in-depth analysis of the area available for restoration was based on three different methodologies, which combine CAR data to represent the rural properties with other sources, estimating the LR to improve existing estimates.

- **Method 1**: CAR data is used to estimate deficits and surpluses for the entire country except in the Amazon biome, where this information is derived from TerraClass.[5]
- **Method 2:** Uses TerraClass to estimate LR deficits and surpluses in the Amazon biome, but for the rest of the country, it uses MapBiomas.[6]
- **Method 3:** deficits and surpluses are estimated using MapBiomas for the entire country.

[3] To access the first results, visit http://bit.ly/2RD6e9C
[4] With the Forest Code in 1965, Legal Reserves were established as areas that define a proportion of rural properties that must be permanently maintained as native vegetation.
[5] https://www.terraclass.gov.br/
[6] http://mapbiomas.org/

The methodologies developed to compute deficits and surpluses were implemented in PostGIS using SQL scripts[7]. This way, it is possible to easily recompute deficits and surpluses as new CAR or land cover data is released. Due to the expected differences among the three methodologies, two scenarios to estimate possible ranges of deficits and surpluses were also analysed:

- **Scenario S_A** estimates the upper bound of surplus for Brazil, by using the lowest deficit and highest surplus among the three methodologies in each municipality
- **Scenario S_B** estimates the lower bound of surplus by computing the highest deficit and the lowest surplus among the three methodologies.

The use of scenarios with ranges of deficits and surpluses ensured that the reality is within this interval. The difference in the outcomes will then point out the importance of this uncertainty. The results shown in Table 6. show that the Amazon biome has the largest deficit and surplus among all methodologies, with values greater than those presented by Imaflora (Guidotti et al. 2017) in a comparative study.

Biome	M_1	M_2	M_3	S_A	S_B	Imaflora
Amazon	13.6	18.2	9.9	4.8	18.7	4.0
Atlantic Forest	3.5	4.2	4.2	1.7	6.0	6.7
Caatinga	0.3	0.3	0.3	0.0	0.5	0.9
Cerrado	5.2	1.4	1.4	0.4	6.2	6.0
Pampa	1.6	0.0	0.0	0.0	1.6	0.7
Pantanal	1.5	0.0	0.0	0.0	1.5	0.0

(a) deficits, in Mha

Biome	M_1	M_2	M_3	S_A	S_B	Imaflora
Amazon	32.5	34.8	64.8	64.9	32.4	11.6
Atlantic Forest	8.5	24.4	24.4	28.4	4.6	8.3
Caatinga	0.6	38.2	38.2	38.2	0.6	34.9
Cerrado	12.5	59.6	59.6	63.8	8.4	43.8
Pampa	0.1	9.1	9.1	9.2	0.1	4.2
Pantanal	0.0	8.3	8.3	8.3	0.0	7.9

(b) surpluses, in Mha.

Table 6 Comparison of (a) deficits and (b) surpluses by biomes, in Mha. Source: de Carvalho et al. 2019

The results presented in this chapter can be used directly as input for different scenarios that investigate impacts of the Forest Code and its possible changes.

4.3 Climate change impacts and land use dynamics

Brazil intends to reduce its GHG emissions by 37% below 2005 levels in 2025 and by 43% in 2030. In 2017 67% of Brazil's emissions came from Land Use Change and Forestry (LUCF) and Agriculture sectors (SEEG 2019)[8]. With its NDC commitments for the LUCF sector, Brazil further intents to enforce the implementation of the Forest Code, at federal, state and municipal level and strengthen other policies and measures to achieve zero illegal deforestation in the Amazon by 2030. It commits to restore and reforest 12 Mha of forests by 2030, for multiple purposes and enhance sustainable native forest management systems through georeferencing and tracking systems applicable to native forest and support management, with a view to curb illegal and unsustainable practices.

[7] The results and scripts can be accessed from http://bit.ly/2ZKaRl2
[8] System for the Estimation of Greenhouse Gases, SEEG Brasil. http://seeg.eco.br/, 2019.

One of the key measures of Brazil's NDC is the enforcement of the Forest Code and the control of illegal deforestation[9] in the Amazon biome. The main program to restore the 12 Mha of forests by 2030 is the National Plan of Native Vegetation Restoration (PLANAVEG). Brazil's NDC targets further include the enhancement of the Low Carbon Emission Agriculture Plan (ABC Plan) with the restoration of 15 Mha of degraded pastureland by 2030, and the expansion of 5 Mha of integrated cropland-livestock-forestry systems (ICLFS) by 2030.

Here, RESTORE+ aims at critically assessing future projections of environmental and agricultural impacts of policies that would reduce emissions from deforestation and increase the use of biofuels. Further the project evaluates climate change impacts in future projections of Brazilian agriculture by performing a set of adaptations and improvements with the GLOBIOM-Brazil model[10]. GLOBIOM-Brazil (as well as the previously mentioned version for Indonesia) is a global bottom-up economic partial equilibrium model that focusses on the main land use economy sectors agriculture, forestry, and bioenergy. The model optimizes over the six land-use classes *Cropland*, *SoyLnd*, *Pasture, Unmanaged forest, Managed forest, Planted forest* (or short-rotation tree plantation) and *Non-productive land* (mosaic of natural vegetation and areas previously converted from agriculture but not currently under production). The default version of GLOBIOM is recursively run with 10-year time steps, starting at the baseline year 2000 through 2050. GLOBIOM-Brazil as used in RESTORE+ has been adapted to run with 5-year time step, allowing for more flexibility and accuracy in defining the starting dates of Brazil's local policy.

Other adaptations include the new land-use class named *Forest regrowth* to simulate the obligatory native vegetation restoration of Brazil's Forest Code. Transitions from *Cropland, Pasture and Non-productive land* to *Forest regrowth* are allowed to compensate for eventual environmental deficits, but no transitions are allowed from *Forest regrowth* to any other land-use class. Land conversion cost is represented by a non-linear function. The cost per converted hectare increases with the total converted area. If production is no longer profitable, land can also be abandoned. *Forest regrowth* areas are set aside only for passive regrowth and the costs of active forest restoration are not considered in the competition for land.

4.3.1 Land use and production impacts of climate change

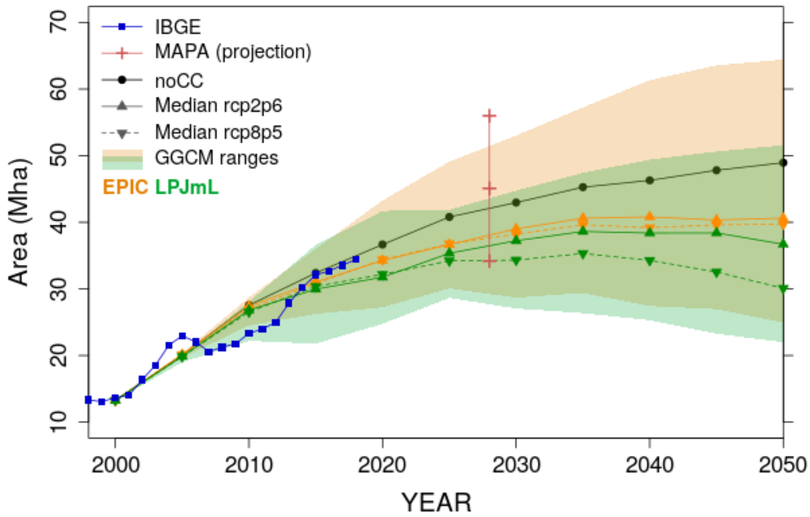
To analyse how climate change could potentially affect land use competition and, consequently, production of the main Brazilian commodities, GLOBIOM-Brazil results for 20 scenarios, resulting from the combination of two emission pathways (RCPs), five climate models (GCMs), and two biophysical models (GGCMs) were examined. Results are aggregated per GGCM and RCP as exemplified here and visualized in **Error! Reference source not found.** for Soybean. The results suggest that Brazilian s oybean production can still grow despite the adverse effects of climate change if the necessary

[9] Illegal deforestation is the clear cut of forests or native vegetation not allowed according to the Forest Code. On the other hand, legal deforestation is the removal of vegetation permitted by this law.

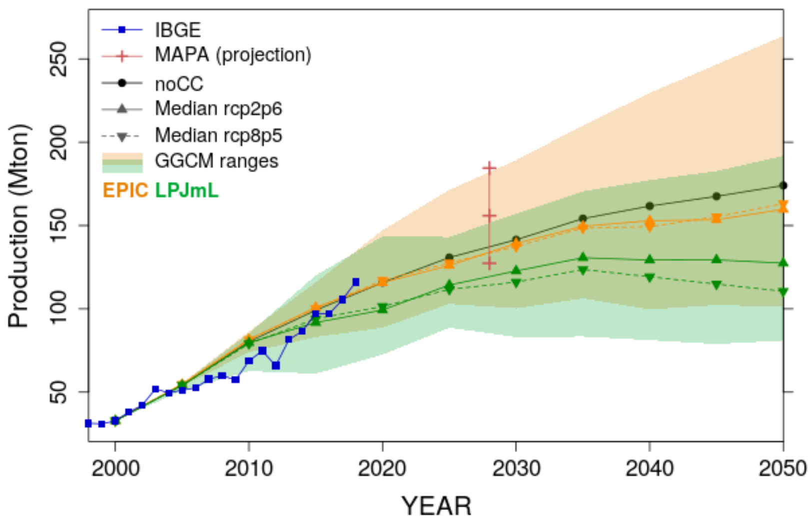
[10] For more details on the improvements and adaptations performed in GLOBIOM-Brazil model in order to implement the scenarios, as well as a validation of the business-as-usual scenario and the refined analysis of the scenarios focusing on land-use changes, agricultural production and emissions reduction regarding the most relevant public and private policies in Brazil, see the dedicated RESTORE+ Project Output V Report (de Carvalho et al. 2019)

technological development is achieved. However, it is important to emphasize that yields projected by GLOBIOM-Brazil are not restricted by any physical parameter and thus may become unrealistic. Even though GLOBIOM-Brazil projected yields for 2028 are within MAPA projections (see red vertical line in **Error! Reference source not found.**c), the necessary technological development in terms of i ncrease of potential productivity may not be physically achievable. A next step will be a deeper analysis of these limitations, involving the analysis of no adaptation scenarios.

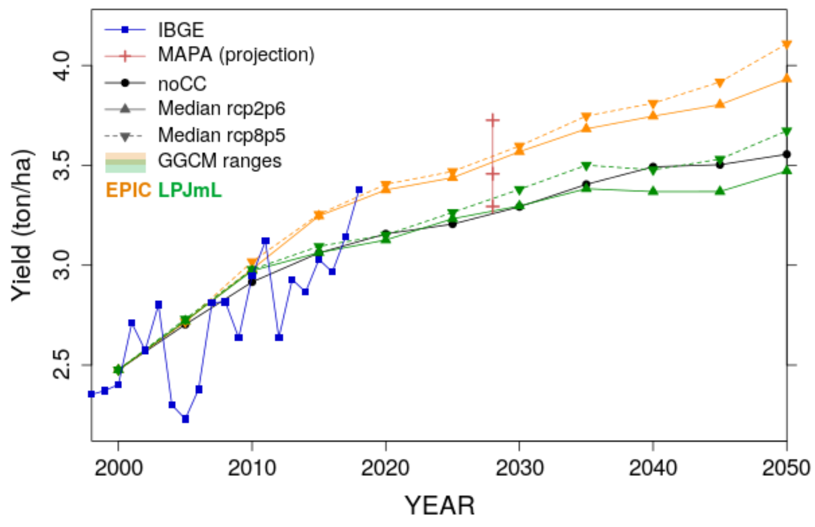
For the evaluation of climate change impacts in future projections of Brazilian agriculture, biophysical shocks that modify crop and grassland productivity were introduced at the beginning of each time step in GLOBIOM-Brazil. These biophysical shocks are estimated through changes in potential productivity projected by crop models forced by projections of future climate change.



(a) soybean area, in Mha



(b) soybean production, in Mton



(c) soybean yield, in ton/ha

Figure 19 Projections of soybean in (a) area, (b) production, and (c) yield aggregated for noCC (black solid line with filled circle), EPIC (orange), and LPJmL (green) scenarios. Solid (dashed) lines and upward (downward) triangles: median values for RCP2.6 (RCP8.5) emission scenarios in each GGCM; Blue line and filled squares: IBGE annual soybean statistics (PAM/IBGE 2019). Red vertical line and crosses: MAPA average projections for soybean in 2028 and its lower and upper limits (MAPA 2018). Orange (green) shaded area in (a) and (b): envelope of scenarios for EPIC (LPJmL), defined by aggregated value of the minimum and maximum scenarios. Source: de Carvalho et al. 2019

As observed for soybean, national corn production is also projected to decrease under climate change scenarios, with the producing areas projected to migrate southward. Despite reproducing the observed area of corn relatively well, GLOBIOM-Brazil underestimates the corn production. This can be attributed, in part, to the representation of the double cropping production system implemented in Brazil.

4.3.2 Land use implications of ethanol demand

Brazil is the world's largest sugarcane producer (FAO 2018), using most of the production as feedstock in the production of sugar and ethanol. The ethanol produced in the country is particularly directed to fulfil the domestic demand for biofuels from the light duty vehicles (LDV) passenger transport sector. Despite the already established ethanol market in Brazil, the government has announced on its NDC to expand biofuels consumption, in order to increase the share of sustainable biofuels in the energy mix up to 18% by 2030 (Brazil 2015).

RESTORE+ estimates three different scenarios of ethanol demand in Brazil towards 2030 by taking three main steps into account: (1) projection of the LDV demand for transport towards 2030; (2) estimation of the future fuel consumption associated to the transportation demand; and (3) modelling of the land-use implications of the ethanol demand development. The different factors considered to define the ethanol demand projections included: (i) population and GDP growth, (ii) demand for light vehicles passenger transport, (iii) default fuel blend mandates, (iv) relative prices between ethanol and the default duel blend, (v) composition of the fleet, and (vi) improvements in fuel consumption efficiency.

Based on this approach, scenarios of macroeconomic and policy drivers that shape the future demand for ethanol in Brazil and their land-use implications were estimated for 2030. Land-use competition was modelled using the detailed partial equilibrium economic model GLOBIOM-Brazil, considering the current land-use policy in Brazil and assuming a scenario of imperfect illegal deforestation control in the Amazon and the Cerrado biomes. Among other specificities, for this study the model includes the *agro-ecological zoning* (AEZ) for sugarcane in Brazil. The AEZ for sugarcane identifies the areas where sugarcane crops can be planted, and areas with restrictions regarding soil, climate, topography, water, and others. It also prohibits sugarcane expansion in ecologically sensitive areas, like the Amazon and the Pantanal biomes. Results on land-use and competition are key information to understand the consequences of increasing the supply of Brazilian ethanol towards 2030 in the context of the Paris Agreement.

The results indicate that ethanol demand could increase between 37.4 and 70.7 billion litres in 2030 depending on the scenario, representing an expansion in sugarcane area between 1.2 and 5 Mha (14%–58% above the land-use in 2018). Compared to the low demand scenario, a high demand for ethanol in 2030 would drive sugarcane expansion mostly into pastureland (72%) and natural vegetation mosaics (19%). Although sugarcane area is substantially smaller than the pastureland area in Brazil, a larger sugarcane expansion would increase to some extent the pressure on pastureland and incentivize higher cattle stocking rates.

Further and regardless the scenario of ethanol demand, sugarcane expansion in Brazil would present no considerable effect in the area or production of other crops. In other words, there is no evidence of competition between sugarcane and other crops simulated by the model since their expansion remains the same in all simulated scenarios.

Moving from the low to high demand scenarios only marginally impact net native vegetation area. Sugarcane expansion in response to higher ethanol demand is expected to take place primarily over pasture and to a lesser extent over non-productive lands. Quantitatively, each additional sugarcane hectare results in a loss of 0.05 ha of native vegetation (72% in the Cerrado and 17% in the Amazon). These results suggest that Brazil can meet future demand for ethanol with limited effects on other crops and native vegetation if the ethanol industry continues to follow the sugarcane AEZ.

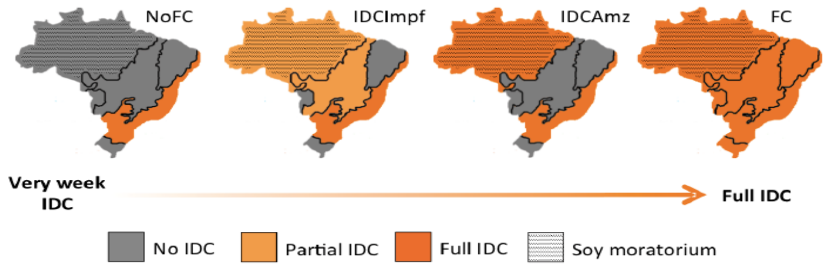
4.4 Land use and restoration policies assessment

Brazilian policies with focus on emissions reduction, such as the goals of the Paris Agreement, are necessarily connected to LUCF and agricultural sectors. In this context, the Forest Code is the key public policy to be investigated. To this end, the question if the enforcement of Brazils Forest Code is enough to achieve the countries NDC and also to reconcile protection and production is being addressed by using a command-and-control scenario that attempts to capture the future impacts of all key provisions of a rigorously enforced Forest Code.

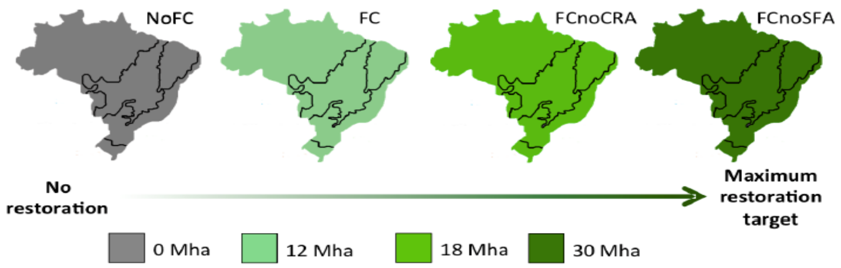
The scenario includes the full control of illegal deforestation (IDC) after 2010, the amnesty of Legal Reserves (LR) debts that happened before 2010 in small farms (SFA), the environmental reserve quota

(CRA) mechanism after 2020, and the mandatory restoration of LR and Areas of Permanent Preservation (APP) debts after 2020.

The counterfactual analysis is a scenario without control of illegal deforestation in all biomes – except for the Atlantic Forest and deforestation for soybean in the Amazon biome after 2006 – and without any requirement for forest restoration (NoFC scenario). The land-use changes are driven by the demand for agricultural commodities. This type of scenario is important for evaluating the losses and gains of an unsustainable future without the enforcement of the Forest Code. Building upon the NoFC scenario, illegal deforestation control is extended from the Atlantic Forest to the Amazon biome (IDCAmz).



(a) Governance gradient



(a) Restoration targets

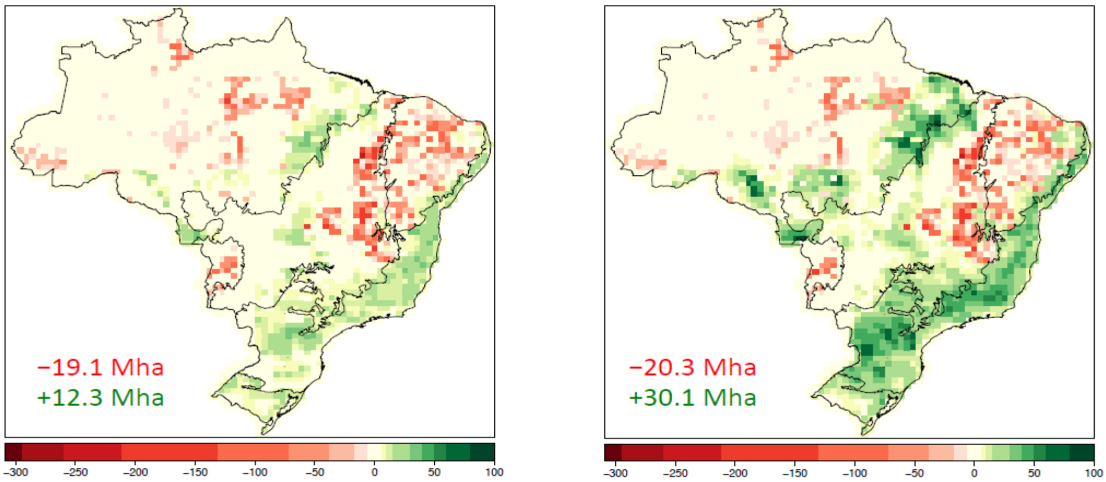
Figure 20 Gradient of governance and restoration targets of the various scenarios. Source: de Carvalho et al. 2019

To test a different level of compliance with the Forest Code, a scenario with a partial illegal deforestation control in the Amazon and the Cerrado biomes was also designed (IDCImpf). In this scenario, the probability of enforcement is based on the enforcement strategy of the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). It is increased by 50% and kept constant during the period 2010-2050. Finally, the role of obligatory forest restoration with IDC and SFA but without any compensation mechanism from the environmental reserve quota system (FCnoCRA), and with IDC and CRA but without the amnesty of small farms (FCnoSFA) was investigated. Figure 20 gives an overview of the scenarios in terms of governance and restoration targets.

Due to the lack of information on property boundaries, the LR surpluses are calculated for each pixel (roughly 50x50 km) as the amount of native vegetation that exceeds the LR requirement.

Environmental debts are based on CAR data downloaded in December 2016 (Guidotti et al. 2017) and upscaled to 50x50 km pixels.

The total environmental debts (derived from CAR data and checked and processed by IMAFLORA) amount to 18.7 Mha in Brazil: 10.8 Mha of LR debts and 7.9 Mha of APP debts. This number is already reduced by the amnesty of small farms. The small farms amnesty is a disposition included in the 2012 revised Forest Code that exempts landowners from the need to recover LR in small properties[11]. Based on the CAR/IMAFLORA data, the total area of environmental debts coming only from small properties would have sum up to additional 18.82 Mha. This area was prevented from restoration due to the amnesty disposition and therefore not considered in the calculation of the environmental debts. Thus, without the amnesty, the environmental debts would be 37.52 Mha.



(a) Forest Code *(b) Forest Code with restoration in small farms*

Figure 21 Large-scale restoration for small farmers: Forest loss (red) or gain (green) between 2015 and 2050 for (a) with Forest Code and (b) Forest Code with restoration in small farms, in million hectares (Mha). Source: de Carvalho et al. 2019

The modelling results consequently indicate the benefit of a large-scale restoration program for small farmers. As Figure 21b shows, this program together with the Forest Code would trigger a potential of about 30 Mha of native vegetation restoration, whereas the rigorous enforcement of the Forest Code alone would result in a native vegetation gain of 12 Mha by 2050 (Figure 21a). In terms of emissions, the large-scale restoration program for small farmers could make Brazil a carbon sink regarding the land-use change and forestry sector by 2035 onwards. Hence, special attention needs to be paid to incentivizing for voluntary restoration by small scale farmers.

4.5 Biodiversity assessment of restoration

Biodiversity analysis constitutes an important element in the assessment of restoration options in Brazil. Potential impacts of forest restoration on biodiversity is assessed by studying land use change

[11] The size limit for small farms is defined by municipality, ranging from 20 ha in the southern Brazil to 440 ha in the Amazon.

impacts on two biodiversity layers: 1) Species habitat change and 2) Biodiversity intactness and their intersection with climate change impacts. (For more details on the methodology see chapter 3.4)

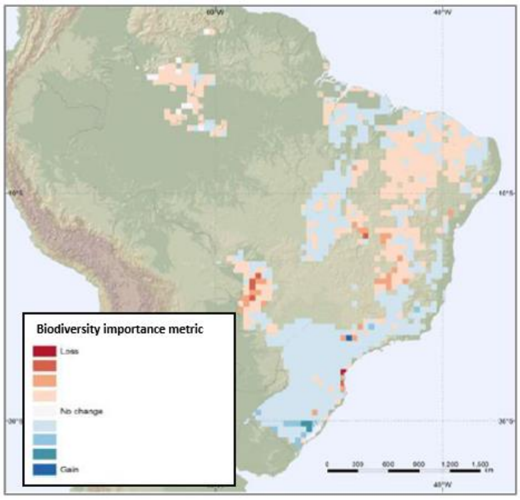
Additionally, in Brazil it is considered how climate change, as a *threat multiplier*, interacts with land use change to influence the fortunes of biodiversity. Through a collaboration with the Tyndall Centre for Climate Change at the University of East Anglia, Norwich, models of future climate change refugia are integrated, developed using the Wallace Initiative Database and the modelling of species climate envelopes. A climate change refugium is defined where over 75% of the modelled species are predicted to have suitable climate conditions in the future. Also for Brazil, the habitat configuration, which effects organism dispersal and genetic exchange, especially under climate change scenarios, will be incorporated into the biodiversity impact modelling.

The first model runs for species habitat change 2020 to 2050 (Figure 22) and biodiversity intactness (Figure 23) have been undertaken for three restoration relevant scenarios for private lands in Brazil:

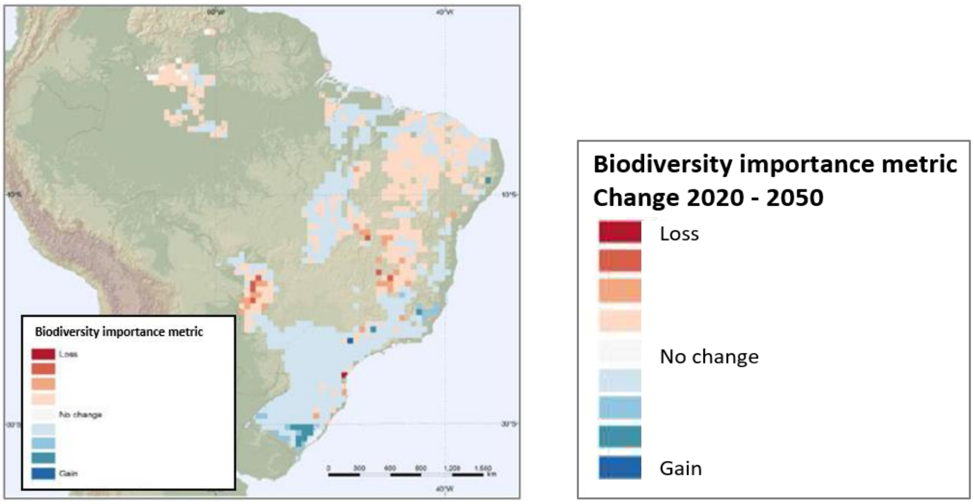
(a) Forest Code Scenario: full implementation of FC (FC)
(b) Forest Code Scenario without environmental reserves quota (FCnoCRA)
(c) Forest Code Scenario with no small farm amnesty (SFA) (FCnoSFA)

The results show the impacts on species of modelled land use change under three scenarios. In each case, the results are masked to highlight changes within predicted climate change refugia for birds, amphibians, and mammals, based on >50% climate change model agreement (n = 21). For species habitat change, it was possible to provide summary statistics on, for example, numbers of species losing > 5% and > 25% of their range under each scenario.

(a) FC Scenario

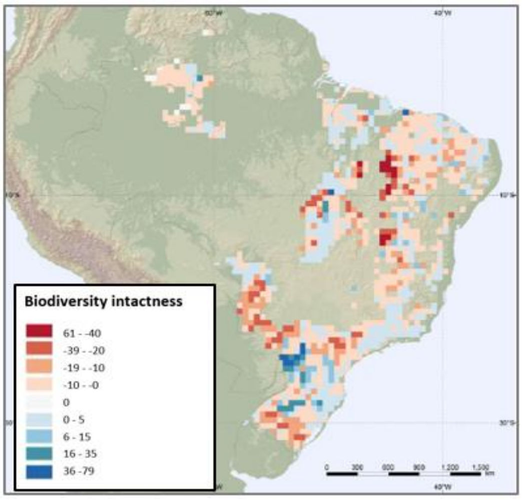


(b) FCnoCRA Scenario

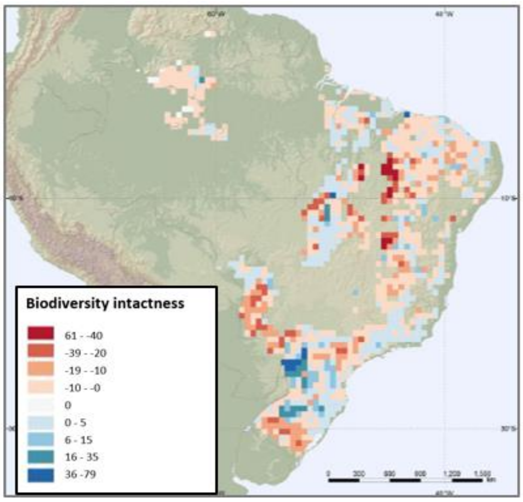


(c) FCnoCSFA Scenario

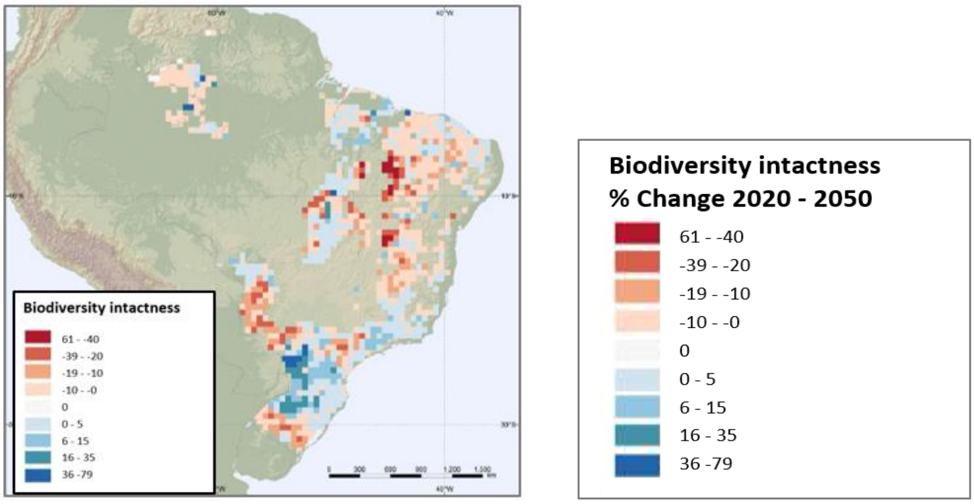
Figure 22 Species habitat change 2020-2050 within climate change refugia for animals in Brazil under three different scenarios of implementation of the Forest Code: (a) FC, (b) FCnoCRA, and (c) FCnoSFA. Darker blue and red colors show 50 km grid cells with most species' habitat gain (blue) and loss (red) respectively. Grey/green shades represent areas outside refugia. Source: RESTORE+ preliminary result



(a) FC Scenario



(b) FCnoCRA Scenario



(c) FCnoCSFA Scenario

Figure 23 Biodiversity intactness in percentage of change from 2020-2050 within climate change refugia for animals in Brazil under three different scenarios of implementation of the Forest Code: (a) FC, (b) FCnoCRA, and (c) FCnoSFA. Darker blue and red colours show 50 km grid cells with most biodiversity intactness gain (blue) and loss (red) respectively. Grey/green shades represent areas outside refugia. Source: RESTORE+ preliminary result

In Figure 24, the impact is expressed as percentage of the assessed species projected to experience different degrees of net change in extent of potential habitat.

As a first conclusion, this shows that the implementation of the Forest Code aids biodiversity. However, biodiversity results can be improved through the removal of the small farms amnesty and/or the compensation of environmental debt.

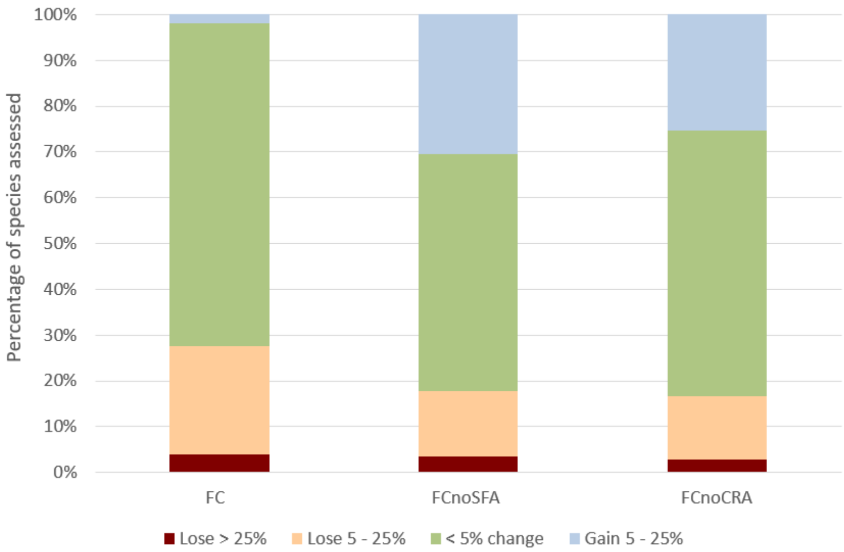


Figure 24 Number of species gaining or losing >5% and >25% of their habitat. Source: RESTORE+ preliminary result

The results are aimed to inform the development of new policy scenarios for restoration. In Brazil next steps will investigate the impact of protected area degazettement, downsizing and degrading.

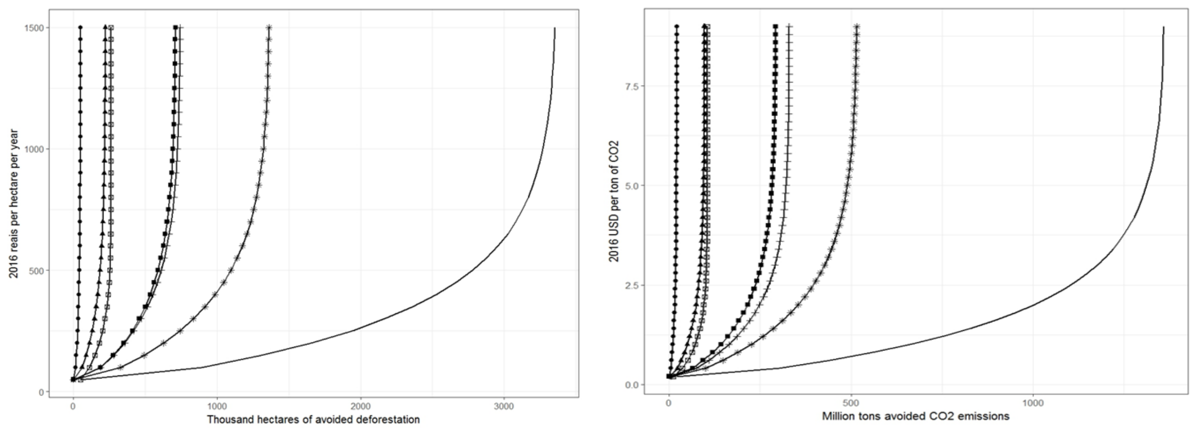
4.6 Restoration opportunity cost analysis

The assessment of opportunity cost and ex-post environmental and well-being impact assessment of policies conducted in RESTORE+ has the objective of identifying scalable financing mechanisms and recommendations for measures of restoration of degraded land.

4.6.1 Restoration and opportunity cost analysis for Mato Grosso

In Brazil, in order to estimate the scale of financial penalties that would halt illegal deforestation and the compensations required to prompt farmers to avoid deforesting areas that can be legally cleared under Brazil's Forest Code, the opportunity cost of all remaining standing forest plots in Mato Grosso, Brazil were quantified through 2030. By coupling opportunity costs of avoiding deforestation with information on carbon stocks and property-level information on forest area relative to legal requirements, CO_2 marginal abatement cost curves for illegal and potentially legal deforestation for each land type were quantified. The cost curves (see Figure 25) can inform deforestation reduction and performance-based REDD+ policies, including the design and proposal of a novel financial compensation mechanism for landowners willing to protect their forest above legal limits.

Building on the opportunity cost modelling for Mato Grosso and literature review of restoration costs across different biomes in Brazil, the restoration costs for properties that are not in compliance with Brazil's Forest Code were estimated and used to assess a potential Environmental Reserve Quotas (CRAs) market in Mato Grosso. This market, envisioned under Brazil's Forest Code, would allow landowners who are required to restore forests on their properties as a result of deforestation before July 2008, to become compliant by supporting forest protection offsite. This approach has the potential to lower the costs of compliance.

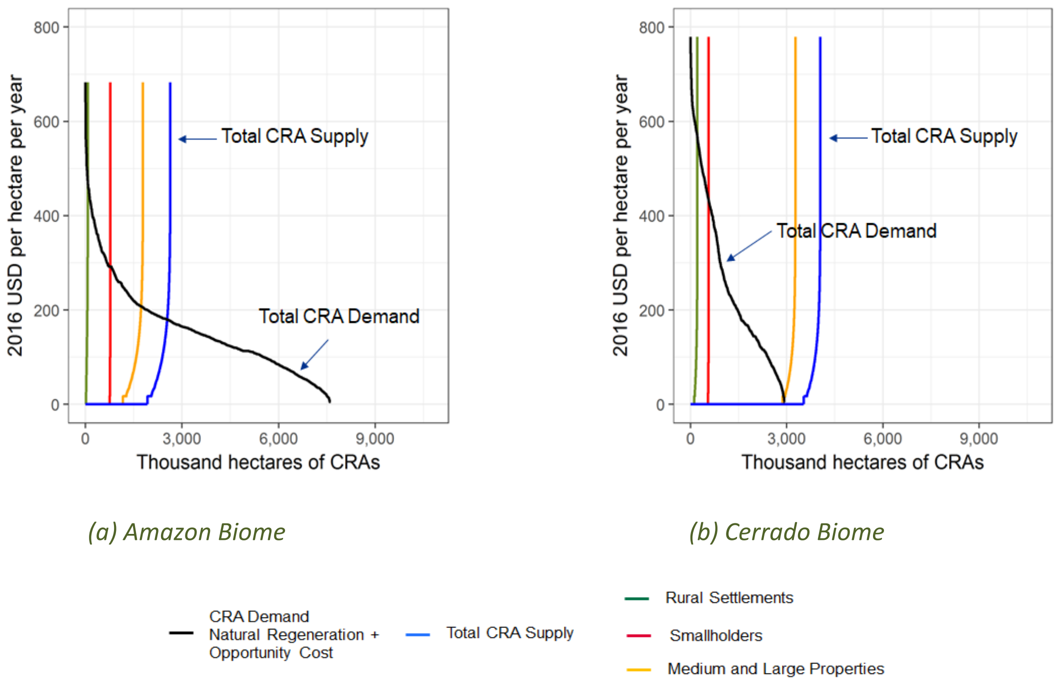


(a) Opportunity Costs

(b) Co2 Marginal Abatement Costs

Figure 25 Opportunity Cost and (b) CO2 Marginal Abatement Cost Curves for Mato Grosso. Source: RESTORE+ preliminary result

The analysis explored how different CRA market designs for Mato Grosso (varying by biome, property size, whether they included interactions with payments for carbon, and by whether they restricted the pool of suppliers to increase avoided deforestation) influence market equilibria and the amount of avoided deforestation as well as reforestation.



(a) Amazon Biome *(b) Cerrado Biome*

Figure 26 Supply and Demand for Environmental Reserve Quotas (CRAs) in Mato Grosso, Brazil; (a) Amazon Biome and (b) Cerrado Biome. Source: RESTORE+ preliminary result

The results show significant differences across the Amazon and the Cerrado biomes. Out of the total deficit, 1.1 Mha need to be restored and 8.7 Mha can either be restored or compensated through the trading of CRAs.

In the Amazon biome in Mato Grosso, the deficit that can be compensated amounts to 7.3 Mha while the surplus is 2.1 Mha. An unrestricted supply would result in a market equilibrium of approximately 2.0 Mha of traded CRAs at a clearing price of 625 BRL/ha/year. This equilibrium leaves 5.3 Mha to be restored. Restricting CRA supply to those hectares at risk of deforestation increases the number of hectares to be restored and increases estimated deforestation avoided. Thus, in the Amazon, a market is likely to successfully achieve avoided deforestation as well as restoration (see Figure 26**Error! Reference source not found.**a).

In the Cerrado biome, the deficit that can be compensated amounts to 1.4 Mha while surplus sums up to 3.9 Mha. This supply of CRAs would drive prices to near zero. Restricting CRA supply only to hectares at risk of deforestation, such as those near existing roads or agricultural land, is fundamental to achieving additional environmental benefits measured by the number of hectares of avoided deforestation and restoration. This excessive supply would make it impossible for the market to achieve ambitious avoided deforestation goals (see Figure 26b) unless supply-side restrictions are imposed, or interstate trading allowed to increase demand. Carbon payments can complement and increase environmental benefits achieved.

In sum, the analysis suggests that (1) different market designs yield different levels of avoided deforestation and restoration, and (2) there can be trade-offs between cost reductions and distributional impacts and environmental gains under this market. To address these trade-offs, targeted REDD+ payments and restoration incentives can be integrated into the CRA market. Thus, follow-up work is currently looking into a more in-depth CRA market analysis for Brazil and the integration of commercial forestry into analysis.

4.6.2 Exploring land-use returns to deliver incentives for restoration in Mato Grosso

Complementing the work on Mato Grosso as described in the above chapter, a novel data set, building on the work of Palmer, Taschini, and Laing (2017) and Engel et al. (2015) is being used. It solidifies the practical application of a real options framework to landowner incentives in Brazilian agriculture, thereby being able to account for the impact of uncertainty on net-returns as well. The purpose of this model is to identify, given a range of data on agricultural returns, the contract structure and payment level, which will achieve the specified conservation probability over the specified time horizon. The model assumes a least-cost approach to conservation – i.e. that Mato Grosso's government is budget-constrained and seeks to maximize conserved forestland area within this budget. Importantly, though carbon storage may be a primary goal, payments in the model relate to landowner opportunity cost. Furthermore, the model assumes that landowners are not good-faith actors – that is, even if they sign up for a conservation payment, if at any point conversion to an alternative land use is more profitable in expectation than continued conservation payments, the landowner will convert their land. Consequently, the model adopts a probability of conservation of 90%.

One of the most important results of this strand of work is a map of the relative cost index (RCI) for the entire region (see **Error! Reference source not found.**Figure 27). For a *Payments for Ecosystems Services* (PES) scheme to incentivize a landowner not to convert their forestland to agricultural land, the payment must be sufficient to outweigh the opportunity cost of the most attractive agricultural activity available to that landowner. Thus, for each municipality, the most important data point is the highest return crop for the landowner. From the perspective of this analysis, that of a PES-funding body such as the government of Mato Grosso, this translates to the highest opportunity cost crop.

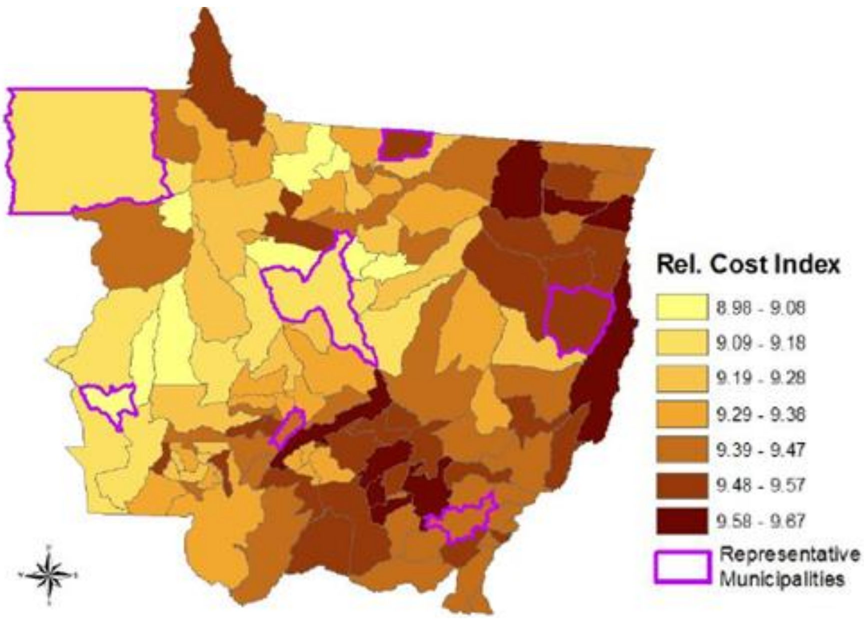


Figure 27 Lighter-coloured, lower-cost municipalities are concentrated in the central, western, and north western regions, while the eastern and southern regions contain the majority of especially high-cost municipalities. Source: RESTORE+ preliminary result

As next steps, data on physical geography characteristics will be identified to generate a new set of conversion costs. Using these new data sets should enable to analyse opportunity costs at the property level or at least to the sub-municipality level (approx. 140 of these in Mato Grosso). Such a detailed, spatially explicit data would allow to model landowner incentives more precisely. The key goal is to estimate conversion costs which have the potential to vary among properties both within and across municipalities.

4.7 Scalable financing for restoration

Within the RESTORE+ project the challenges for financing forest conservation and restoration, as well as potential solutions are being investigated. In terms of challenges, forest investments tend to have a long horizon and a relatively small scale which makes them less attractive to large investors, and often projects are perceived to be risky. Moreover, it is challenging to leverage the public benefits provided by forests for financing purposes. In this regard, REDD+ payments for carbon sequestration and avoided emissions could play a critical role but the market needs further development. Despite the opportunity to mobilize private markets for large-scale efforts to protect tropical forests based on Article 6 of the Paris Agreement and although REDD+ payments have the potential to provide considerable resources for large-scale forest conservation and restoration, there are several factors that currently limit the scalability and impact of the program and pose a challenge to scale up financial mechanisms for restoration:

- Difficulty for buyers to connect and transact with jurisdictional level programs
- Challenge for buyers to invest, given uncertainty over future policy and lack of market standards
- Challenge for REDD+ programs to garner necessary investment and political support without long-term demand

- Perception that jurisdictional scale is only for 'donor' capital
- Lack of a tradeable unit verified to a high-integrity standard that aligns with international policy framework (Paris and Warsaw)

With respect to solutions, innovative financial instruments to address concerns around investment risks have been implemented already in different regions and continue to be tested. These include enhanced bonds that leverage donor funding to lower the cost of capital for borrowers, the use of first loss or investment guarantees to lower risks to investors and attracting impact investors and philanthropies that tend to have longer investment horizons.

Here the focus has been on accelerating large-scale jurisdictional forest conservation and restoration by facilitating transactions of high-integrity credits between jurisdictional REDD+ programs and private buyers. To help support such transactions, an intermediary has been developed that will provide guaranteed demand to programs, so as to support large-scale carbon credit supply, and that will aggregate private buyers in order to facilitate transactions - *Emergent Forest Finance Accelerator*; *Emergent*. This will make use of a new standard for jurisdictional REDD+ programs and related market infrastructure that ensures consistency and registers, verifies and issues high-quality, serialized credits - *Architecture for REDD+ Transactions; ART.*

Emergent is a new, not-for profit entity launched in September 2019 during UN Climate Week that combines public and private finance to facilitate transactions of high-quality credits between jurisdictional REDD+ programs and private buyers. Its mission is to maximize environmental benefits along with sustainable economic development from tropical forest protection. Emergent is supported by a consortium including EDF, Norway's International Climate and Forest Initiative, Packard Foundation, Rockefeller Foundation, and Good Energies Foundation.

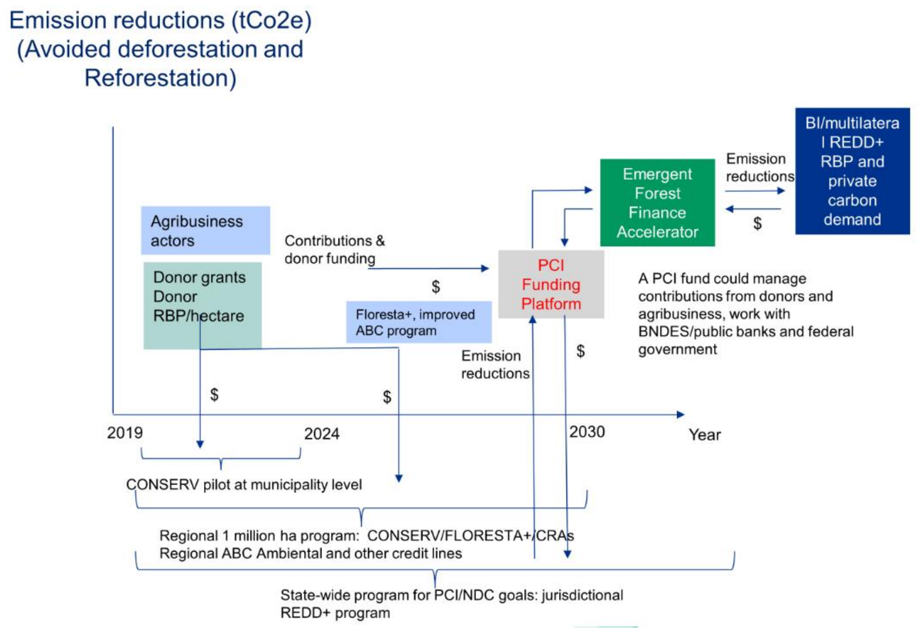


Figure 28 Integrated Financing Strategy for Mato Grosso. Source: RESTORE+ preliminary result

Collaborators of this work under RESTORE+ have developed an integrated finance strategy that combines such potential sources of REDD+ demand and other instruments to support the state of Mato Grosso in implementing its Produce, Conserve and Include (PCI) sustainable rural development strategy. The strategic plan combines different funding sources and geographic scales over time and other initiatives such as *Agricultura de Baixo Carbono* (ABC) Program, Floresta+, CONSERV, and policies like the CRA market into a larger jurisdictional REDD+ strategy (Figure 28).

5. Supporting evidence-based land use policy making in the Congo Basin

In the Congo Basin, RESTORE+ activities pursue the goal of ensuring sustainable impact of land use change projections for the Congo Basin region that were generated by the preceding REDD-PAC project. Different to other tropical countries such as Brazil and Indonesia, for the forest-rich countries of the Congo Basin, halting deforestation is of utmost importance, where restoration still plays a minor role. Here, avoided deforestation offers a large and very cost-effective potential to curb greenhouse gas emissions. This requires the development of a credible benchmark to compare efforts to halt deforestation. Those benchmarks should be considering future societal and economic development to define how much would be emitted in the absence of REDD+ (Reducing Emissions from Deforestation and forest Degradation) interventions to halt deforestation. This benchmark is called a *forest reference level* (FRL) or *forest reference emission level* (FREL) and is adjusted to account for the dynamic socio-economic development using a land use model.

Building on land use change projections for the Congo Basin region generated by REDD-PAC, RESTORE+ applies its tools and incorporates newly available authoritative datasets on degraded areas, for land cover development and national forest inventory data to develop improved land cover change maps (so called activity data) and emission factors, respectively, for Cameroon. To generate technical recommendations and gain endorsement from relevant policy makers and other stakeholders of the Congo Basin region, the project activities aim at tailoring these methodologies and tools developed during REDD-PAC to the policy processes relating to climate change mitigation and conservation of biodiversity. To this end, also selected training activities were conducted throughout the project which result in enhanced capacities of local stakeholders and contribute to disseminating activities by key regional and national actors in the Congo Basin region.

Another component of methodological development pursued under RESTORE+ is the analysis of uncertainties associated with the calculation of a FREL, as stipulated by the IPCC Guidelines for National Greenhouse Gas Inventories and required by performance-based payment schemes like the Carbon Fund. To that end, a Monte Carlo Analysis encompassing land cover maps, forest inventory data and adjustment of the reference level to future development pathways was set up and performed and results reported to the Technical REDD+ secretariat. In a nutshell, the land use model seeks at projecting societal megatrends such as urbanization, population growth and modest wealth growth to the future and estimates the impacts of these on future emissions from land use.

With the adjustment of the FREL to these societal megatrends (see top bar in Figure 29), RESTORE+ demonstrated what can be done with available information and data, and outlines pathways to further improve the quality of future FREL's, considering possibly accessing performance-based payments. The elaboration of the reference emissions level and the projected emissions reductions contributed to the Southern Cameroon Plateau REDD+ project, where the government of Cameroon is seeking to sell carbon credits to the payment for ecosystem services scheme of the Carbon Fund Reductions Programme Document (ER-PD) for the Southern Cameroon REDD Programme for submission to the Forest Carbon Partnership Facility (FCPF).

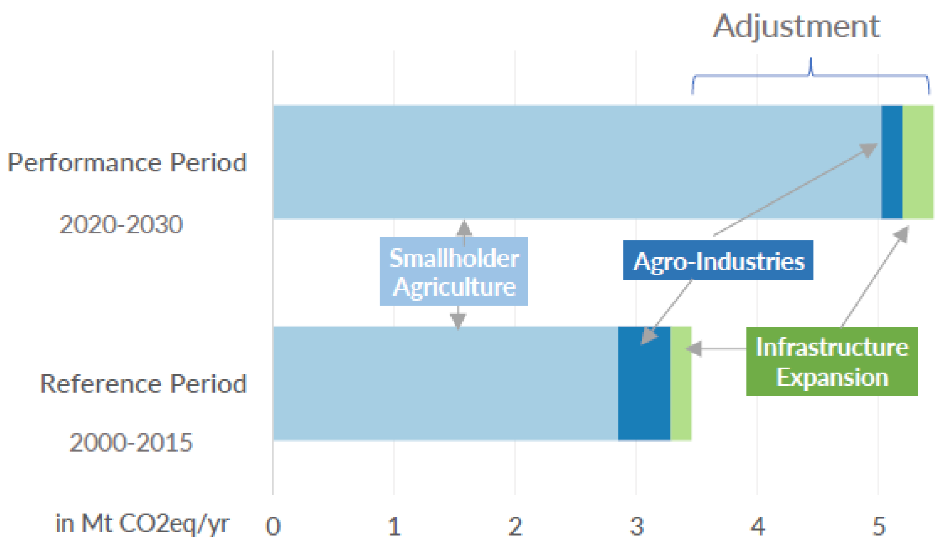


Figure 29 Projected emissions during the performance period with adjustment to societal megatrends (top bar) are 29% higher than emissions during the reference period (bottom bar); the increase is driven by expanding smallholder agriculture for which emissions are projected to increase by 48%. Source: Pirker et al. 2019

As the results show, the emission level for the period 2020-2030 is estimated to be 29% higher (see Figure 29) compared to the virtual reference period 2000-2015. Deforestation during this initial period is dominated by non-industrial agriculture (comprising both smallholders and local elites) and increases over time.

The land use model projections are consistent with this trend, resulting in emissions that are on average 47% higher during the virtual performance period 2020-2030 than during the reference period 2000-2015. This over-proportional development of emissions is due to increased expansion of staple crops with little carbon remaining on site. The Monte Carlo analysis points to the adjustment term as the main driver of uncertainty in the FREL calculation.

In general, the results of the Monte Carlo analysis suggest that the uncertainty underlying the calculations are within reasonable bounds (see Figure 30); the adjustment term comes out as the main driver of uncertainty. After internal revision of the entire ER-PD by the FCPF in April 2019, it was decided to not accept the available document for further evaluation by the independent Technical Assessment Panel (TAP), the reason being that the GHG monitoring system was considered not a robust basis for payments for emissions reductions. Discussions are ongoing to expand the approach to determining reference levels to the national scale to define the national FREL for submission to the UNFCCC.

The results of the analysis show that the available data is suitable for constructing a FREL for periodic reporting to the UNFCCC. However, enhancement of quality and coherence of input data (notably for activity data and the model-based adjustment) is needed to apply for a performance-based payment scheme. Expanding the accounting framework to include forest degradation and forest gain are further priorities requiring future research.

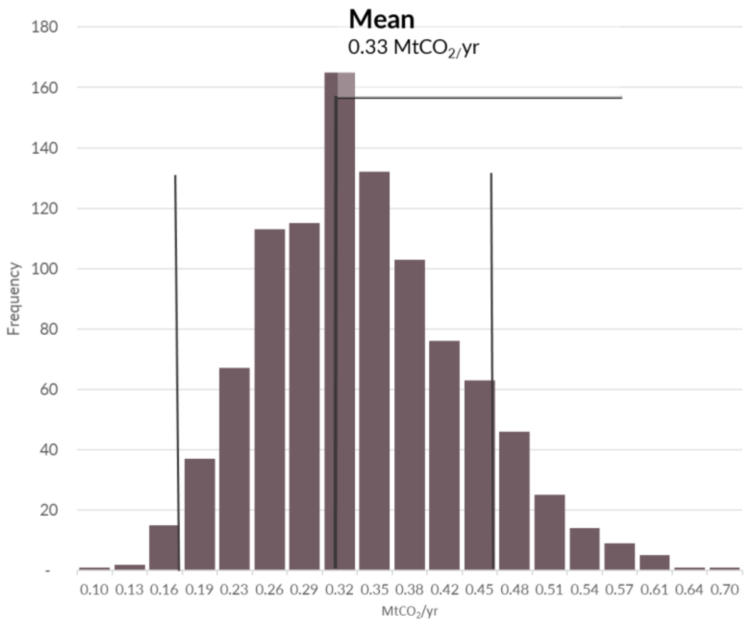


Figure 30 Representation of 1000 runs of reference level calculations – an outcome of the Monte Carlo analysis. The bold black line indicates the mean, thin black lines the 2-tailed standard deviation at α=0.05. Source: Pirker et al. 2019

Co-authored by REDD+ policy makers in Cameroon, the experience of the work on REDD+ are documented in a research article by Pirker et al. (2019) entitled *Determining a Carbon Reference Level for a high- forest-low-deforestation country*, which contains a critical review of the status quo of GHG monitoring in Cameroon[12].

[12] Full publication can be accessed from http://www.restoreplus.org/uploads/1/0/4/5/104525257/pirker_et_al._forests-10-01095.pdf

6. Going forward

RESTORE+ will continue to address the two fundamental questions of restoration in informing decision makers related to large-scale restoration. The project will remain confronting the complexity of restoration with approaches that are inclusive to the heterogeneity of landscape degradation and restoration potential, as well as diverse interventions that will be specific to site-specific socio-ecological restoration objectives. Furthermore, the project will also incorporate views gathered from mid-term stakeholder consultation in Foz do Iguaçu.

Linking large scale targets with site-specific solutions

Decision makers (e.g. national or regional governments, funding agencies, international coorporations) need to be able to link aggregated targets that use generic indicators with restoration solutions that vary widely depending on site-specifc challenges and objectives. The acknowledgement of no one-size-fits-all solution needs to be accompanied with explicit and measurable indicators to these diverse solutions which will allow stakeholders to connect and/or compare the performance of restoration activities in different sites.

Knowledge gap on restoration options and their associated costs and benefits

RESTORE+ project stakeholders confirmed the need to address knowledge gap on restoration options, particularly in identifying cost effective options to address specific landscape challenges. Most restoration projects begin with the identification of landscape degradation or objectives of enhancing certain aspect of ecosystem services in the area. Suitable options that can properly address these initial conditions may require investigations that present a challenge to those restoration projects. Limitations and potential trade-offs of intervention options are also an area that needs further insights. Moreover, the costs of the options are rarely clearly known at the beginning of a project with additional costs of restoration measures getting revealed as the project unfolds.

Unlocking access to funds

The high cost of restoration, particularly when also considering the opportunity cost of other land uses of the landscape, is still identified as a major barrier. In Brazil, lack of funding remains a major barrier despite progresses in establishing legal framework and technological solutions for restoration. Viable business models are yet to be identified to ultimately address the funding issue. Alternatively, environmental markets could play an important role in providing the necessary funds for restoration. Assessing the true cost of restoration (i.e. including transactional, operational and opportunity costs) will be key in informing necessary mechanisms and actors for such an environmental market.

Delivery mechanism for large scale restoration activities

The heterogeneity of restoration activities also poses questions to institutional roles and their interaction in implementation. Landscape interventions may require cross-border governance with support or supervision from multiple government actors. Lack of clarity in delivery mechanism also suffers from existing knowoledge gap on restoration options and the relationship between site-specific solutions and aggregated large-scale targets.

Potential of agroforestry as a financially viable restoration measure

Agroforestry have emerged in the discussions as a potentially viable solution as it has the ability to deliver environmental benefits while at the same time generating income for landowners. Agroforestry can also serve as an entry point for further restoration measures since the benefit of keeping standing forests can be more tangible. However, special caution is required towards its potential to also encroach conservation areas.

A strong business case with more information on the return of agroforestry systems is still needed, along with more information on priority/potential areas and appropriate measures needed to mobilize investments in agroforestry systems.

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