World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

Palm oil series

# The carbon efficiency of oil palm plantations: an opportunity cost analysis

The introduction and expansion of oil palm in Indonesia reflects the crop's economic attractiveness and benefits, but the social interactions between companies and local communities have had a mixed track record that requires attention. To some extent, oil palm plantations have been portrayed as costly from social and environmental perspectives.
To understand the economic benefits of palm oil production, we analyzed both private and financial returns at the plantation level as well as the return to labour. Socially, interaction areas were identified as the result of labour requirements of oil palm plantations and the profitability of independent and plasma smallholders' plantations.

| Main findings | Implications |
|---|---|
| 1. Emissions from conversion of forests to plantations, on mineral soil only, range 2.5–32.7 ton $CO_2$eq/(ha.yr)<br><br>Emissions from conversion of forests to plantations, on some peatland, range 12.33–73.6 ton $CO_2$eq/(ha.yr) | If the same pattern persisted after 2008, the companies would be held responsible for this carbon debt; conversion before 2008 is 'grandfathered' (current rules don't apply) |
| 2. The carbon efficiency (<USD5/t$CO_2$eq–>USD20/t$CO_2$eq) varies within and between plantations | In high carbon-efficient plantations, 'carbon markets' are not expected to influence decisions to initiate similar conversions in the future. In low carbon-efficiency plantations, a large proportion of emissions can be readily 'bought out' as affordable carbon costs |
| 3. Typology of carbon efficiency derived from the study: 1) plantations with low emissions and high carbon-efficiency (LE-HC); 2) plantations with low-to-medium emissions and medium carbon-efficiency (ME-MC); and 3) plantations with high emissions and low carbon-efficiency (HE-LC) | The typology of carbon efficiency can guide policy development on broader land use planning for low emissions development |
| 4. Carbon efficiency versus emissions savings: carbon efficiency and emissions savings reflect different scales and assumptions; they are not totally related empirically | This provides a way to reconcile international and local/national ways of defining the sustainability and 'greenness' of a product. Emission saving is a more relevant indicator for the greenness at the international level, while carbon efficiency is more relevant towards land use planning for low emission development at the local and regional levels |
| 5. Dynamic of carbon efficiency: NPV and percentage of forest lost are highly significant correlations, while soil type is significantly correlated to carbon efficiency | Increasing carbon efficiency can be achieved through the improvement in NPV (higher productivity, less input, higher price) and/or reducing emissions through avoiding forest conversion, and most importantly, avoiding peatland conversion |

## Introduction

The analysis of opportunity costs in the context of climate-change mitigation actions in the Agriculture, Forestry and Land Use (AFOLU) sector aims to estimate the cost of compensating forgone opportunities if a land-based carbon-emitting activity is abated[1]. The analysis recognizes the trade-off between emissions and financial gain. The opportunity cost of land-use change is defined as the amount of financial gain per ton of carbon dioxide equivalent ($CO_2$eq) emitted from a particular change in land use. The higher the financial gain (for example, in USD) per ton $CO_2$eq emitted, then the higher the opportunity cost. A higher opportunity cost implies a higher cost of abating the emissions caused by the land-use change. Opportunity costs are estimated, at the level of a land-use system, per unit area and aggregated to the larger level of a landscape to construct an abatement cost curve. At the landscape level, the analysis deals with all land-use systems (AFOLU) simultaneously.

In the context of this study, we did not aim to estimate the cost of abating emissions or avoiding deforestation/degradation as such. We focused, rather, on the potential for increasing carbon efficiency (improving the ratio between profit and emissions and increasing profit while reducing emissions). Land-use efficiency with regard to carbon emissions is part of a low emissions development strategy under a broader climate-change mitigation action, which is a common responsibility agreed among nations through the United Nations Framework Convention on Climate Change. This is especially relevant for Indonesia, with its 2009 presidential commitment to significantly reduce emissions. However, we must also recognize the need for economic growth and equitable livelihoods.

In this brief, we refer to the results of the opportunity cost analysis as 'carbon efficiency of plantations' rather than 'opportunity cost of plantations' to avoid potential confusion.

## Objectives

The objectives of the analysis were to:

1) develop a methodology to measure the carbon efficiency of a plantation;

2) compare in a retrospective analysis the carbon efficiency of 23 sample plantations and the factors affecting them; and

3) recommend regulations and practices to increase carbon efficiency for existing and future oil palm plantations across Indonesia, based on the practices and performances of the 23 sample plantations.

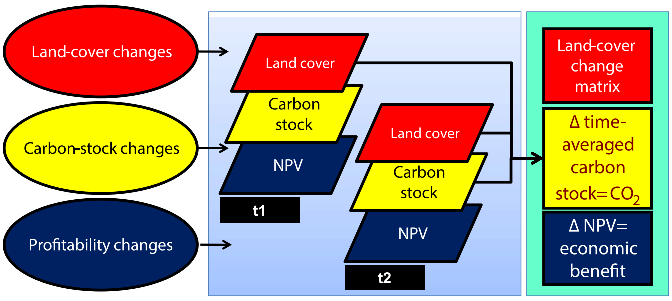
## Methodology

The opportunity cost analysis of oil palm production was conducted at the level of nucleus plantations. It integrated the three main components of analysis (Figure 1):

1) Land-use and land-cover change analysis to quantify the areas of change of each pair of land-use systems found in the nucleus area of the plantations, from the earliest time step ($T_O$) to the most recent ($T_N$) (ha) using ALUCT (see Technical Brief 25 in this series).

2) Time-averaged carbon stock (ton/ha) for each dominant land-use system that could be found in the nucleus area, using Rapid Carbon Stock Appraisal (RaCSA) (see Technical Brief 25 in this series).

3) Financial gain (in private NPV) for each land-use system (USD/ha) using PAM (see Technical Brief 26 in this series).




$$\text{Opportunity cost} = \frac{\Delta\ NPV}{\Delta\ CO_{2\text{-}eq}}$$

Figure 1. Opportunity cost analysis of emissions from AFOLU

The opportunity cost of each pair of land-use conversions is the difference between the NPV of the new land use at $T_N$ with the original land use at $T_O$ divided by the $CO_2$eq of carbon stock lost from the original land use. By sorting the opportunity costs in descending order and plotting the cumulative emissions ($CO_2$eq/(ha.yr)) in the x-axis and the opportunity cost in the y-axis, we produced a generic abatement cost curve or, in the case of this analysis, of oil palm production in the nucleus areas: the carbon-efficiency curve. At the plantation level, carbon efficiency was calculated from total NPV divided by total net emissions in the whole nucleus area.

The calculation, analysis and construction of the carbon-efficiency curve were conducted mainly in open source software called ABACUS[ii], which was developed by the World Agroforestry Centre.

## Sample profile

Selection of plantations for data collection followed a stepwise cluster approach, soliciting self-nomination of companies to become involved in learning the method while helping to collect the data. The stepwise sampling design used three main criteria: 1) initial land use categorized into forest and non-forest; 2) soil type categorized into peat and mineral soil; and 3) relative density of oil palm in the relevant province.

Based on these three main criteria, a total of 12 clusters (strata) were defined as the basis for a stratified sampling approach (Figure 2 and Table 1). Based on nominations of candidates for study sites by plantation companies, the most important strata were able to be covered with replicate samples, but clusters such as 'peat, non-forest history' were not represented in the final selection of 23 plantations.

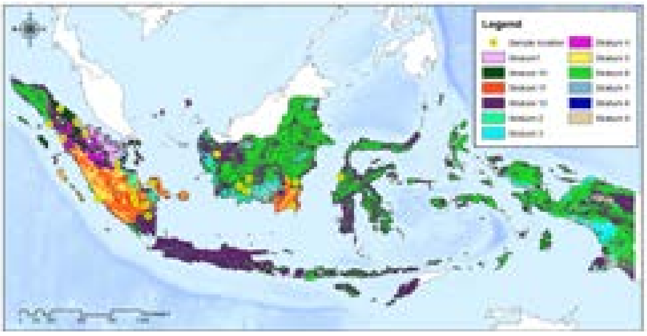


Figure 2. Sample distribution of oil palm plantations

Table 1. Sample distribution of oil palm plantations by cluster based on parameters of former land use, soil and density of oil palm in the province

| Sample parameters | | | Cluster name | Number of sample |
|---|---|---|---|---|
| **Initial land use** | **Soil** | **Area density of oil palm** | | |
| Forest | Peat | Density 1 | Cluster 1 | 2 |
| | | Density 2 | Cluster 2 | 2 |
| | | Density 3 | Cluster 3 | 1 |
| | Non-peat | Density 1 | Cluster 4 | 2 |
| | | Density 2 | Cluster 5 | 3 |
| | | Density 3 | Cluster 6 | 8 |
| Non-forest | Peat | Density 1 | Cluster 7 | |
| | | Density 2 | Cluster 8 | |
| | | Density 3 | Cluster 9 | |
| | Non-peat | Density 1 | Cluster 10 | 2 |
| | | Density 2 | Cluster 11 | 3 |
| | | Density 3 | Cluster 12 | |
| | | Total sample plantations | | 23 |

## Main findings

### 1. Emissions from conversion and peat

Emissions from conversion of forests for plantations ranged 2.5–32.7 ton $CO_2$eq/(ha.yr) across the 15 plantations that had only mineral soil as substrate. The source of the variation was mainly the original forest cover and aboveground carbon stock prior to establishment.

Emissions from conversion for plantations and continuing emissions from the drained peatland ranged 12.33–73.6 ton $CO_2$eq/(ha.yr) across the eight plantations that had some peatland. Emissions varied by the percentage of peat within the plantations in combination with the original aboveground carbon stock (Figure 3).

### 2. Do emissions always correspond with real financial gain? The carbon efficiency ($<$USD5/t$CO_2$eq–$>$USD20/t$CO_2$eq) varied within and between plantations

The opportunity costs were calculated for each change of land use for each zone (mineral and peat) (Figure 4b). The quantity of emissions associated with a particular level of opportunity cost were quantified. This analysis provides the first approximation of carbon efficiency and abatement costs and is a step towards making general comparisons across sectors (for example, energy and waste) that produce greenhouse gases and have carbon on international carbon markets.

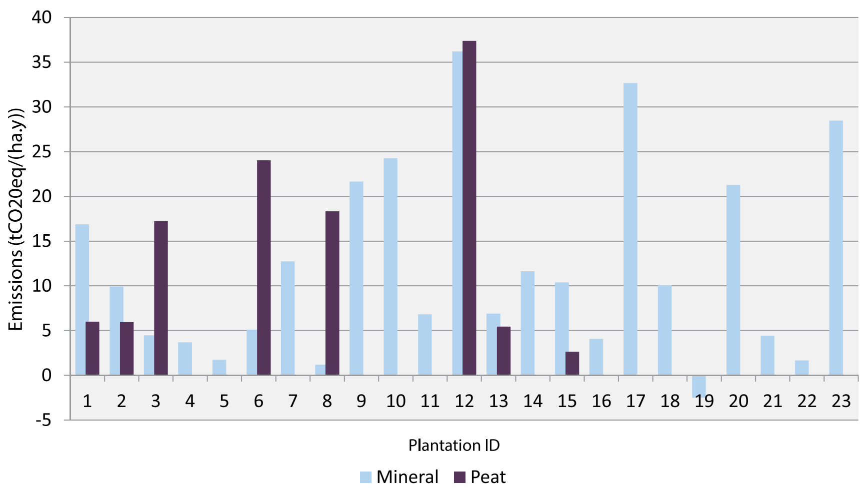



Figure 3. Emissions from mineral and peat areas within each plantation that were converted to oil palm, taking into account continuing peat emissions after conversion

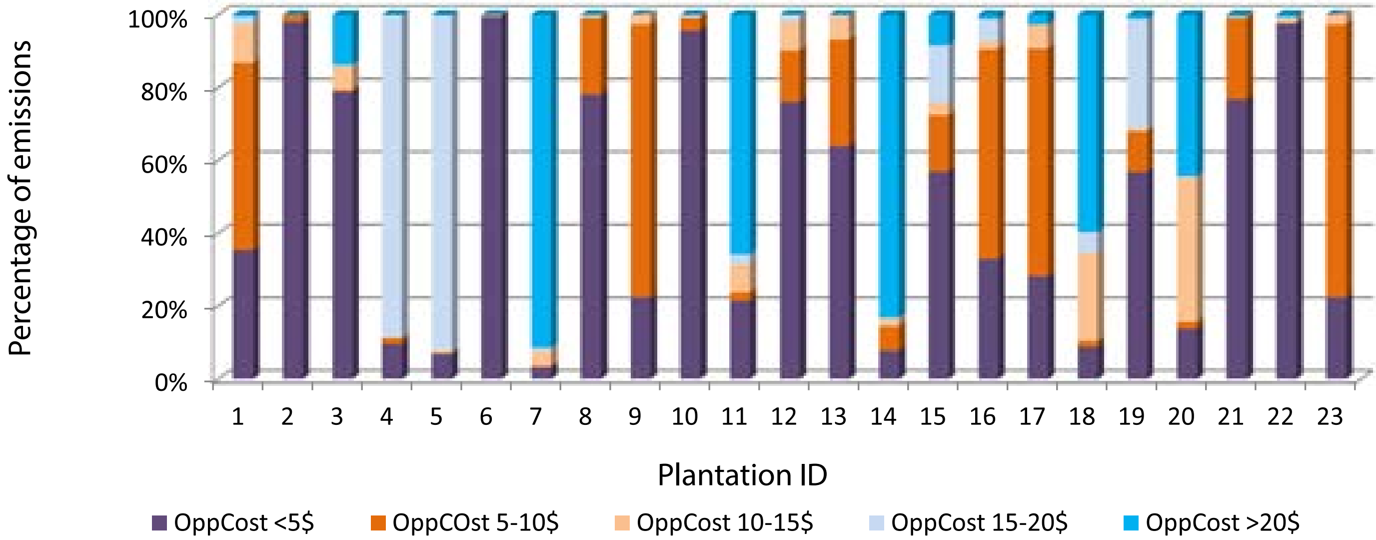



**Figure 4a. Fractions of emissions associated with several ranges of opportunity costs for each plantation**

We derived five classes of emissions, based on the financial gain brought per unit of emission: 1) < USD5/$tCO_2eq$; 2) USD5–10/$tCO_2eq$; 3) USD10–15USD/$tCO_2eq$; 4) USD15–20/$tCO_2eq$; and 5) > USD20/$tCO_2eq$.

Using these classes to assess the relationship between emissions and financial gain across the sample plantations revealed significant variation between plantations (Figure 4a). The proportion of emissions associated with a profit of less than USD5/$tCO_2eq$ emission varied between 3.2% (for highly carbon-efficient plantations) and 99.9% (for less carbon-efficient plantations). For the most carbon-efficient plantation, only 8.6% of emissions were associated with less than USD20/$tCO_2eq$ emission.

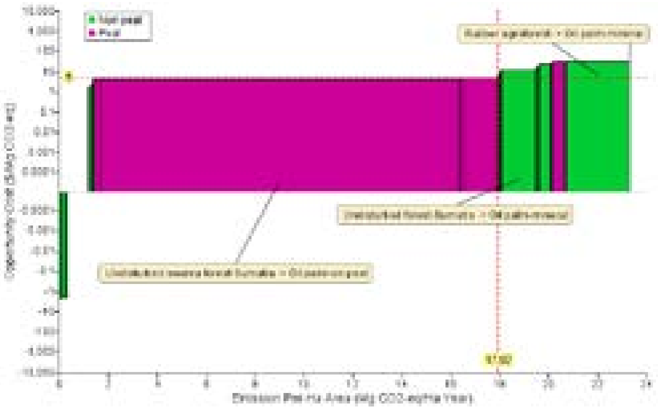


**Figure 4b. Example of abatement-cost, or carbon-efficiency, curve**

## 3. Typology of carbon efficiency: plantations versus annual net emissions

We derived a typology of plantations that categorized them based on their total emissions and carbon efficiency. Based on the results of the analysis of the 23 sample plantations, we suggest three classes of plantation based on total emissions and three classes of carbon efficiency (Figure 5 dan Table 2):

1) Plantations with low emissions and high carbon-efficiency (LE-HC) are shaded in green. A very small portion of emissions can potentially be abated. Most of these plantations had low aboveground carbon stock to begin with.

2) Those plantations with low-to-medium emissions and medium carbon-efficiency (ME-MC) are shaded in yellow. Plantations under this category show medium potential for abatement. Plantations either originally had high aboveground carbon stock but highly profitable plantations per unit of emission or originally had medium aboveground carbon stock with medium return per unit of emission.

3) Plantations with high emissions and low carbon-efficiency (the financial gain per unit of carbon emitted is low) (HE-LC) are shaded in red. Most plantations with mixed soil fall into the category of medium-to-high emissions

**Table 2. Typology of plantations based on emissions and carbon efficiency**

| | Low emissions: < 20 $tCO_2eq$/(ha.yr) | Medium emissions: 20–40 $tCO_2eq$/(ha.yr) | High emissions: > 40 $tCO_2eq$/(ha.yr) |
|---|---|---|---|
| Low efficiency: < USD20/$tCO_2eq$ | | #01, #02, #06, #08, #09, #010, #013, #016, #017, #023 | #012 |
| Medium efficiency: USD10–20/$tCO_2eq$ | | #03, #015, #020, #021, #022 | |
| High efficiency: > USD20/$tCO_2eq$ | #04, #05, #07, #011, #014, #018, #019 | | |

and low carbon-efficiency (ME-LC), shaded in purple. These plantations show high potential for abatement: those with high aboveground carbon stock at the beginning or those with mixed mineral and peat soils that cause high emissions with relatively low NPV increments.

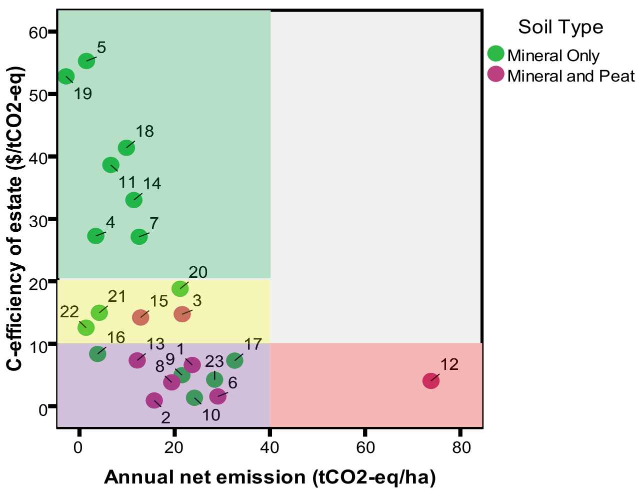



Figure 5. Carbon efficiency of each plantation plotted against annual net emissions. The labels shown are plantation ID

## 4. Carbon efficiency versus NPV: plantations with a higher NPV tend to have higher carbon efficiency

Plantations with a higher NPV of oil palm per hectare also tended to have higher efficiency of carbon emissions, but the same level of NPV could also bring variable carbon-efficiency at the wider plantation level (Figure 6). The relationship was stronger for plantations on mixed soils.

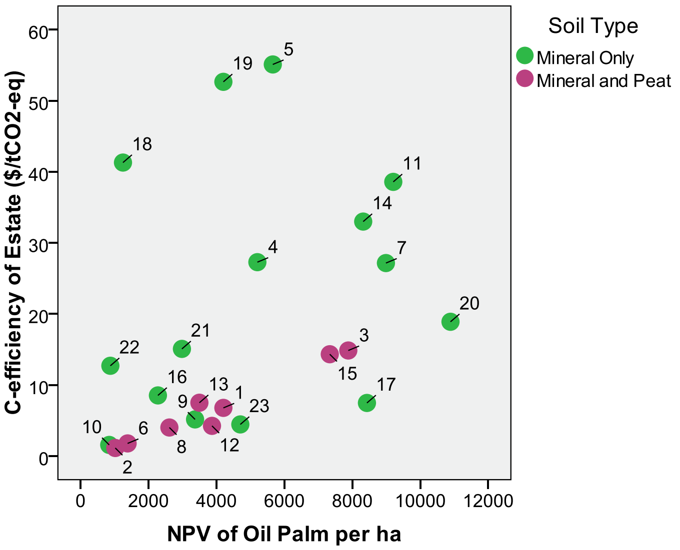



Figure 6. Emissions savings of biofuel from oil palm with the carbon efficiency of plantations. The labels shown are plantation IDs

## 5. Carbon efficiency versus emissions savings: carbon efficiency and emissions savings reflect different scales and assumptions; they are not totally related empirically

When carbon efficiency of a plantation is low (less than USD20/t$CO_2$eq), increased efficiency correlates strongly and positively with emissions savings (solid blue line) (Figure ). As carbon efficiency is higher, the correlation is less marked, but remains strong and positive (solid red line). This shows that even though the two measures reflect different scales and assumptions, they are not totally related empirically. This provides a way to reconcile international and local/national ways of defining the sustainability and 'greenness' of a product, in this case, oil palm.

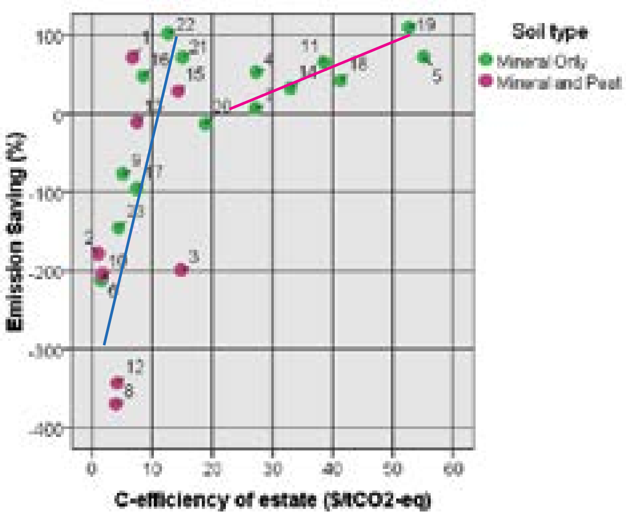



Figure 7. Emissions savings of biofuel from oil palm with the carbon efficiency of plantations. The labels shown are plantation IDs

## 6. The dynamic of carbon efficiency of plantations

The most parsimonious regression model uses carbon efficiency at the plantation level as the dependent variable and NPV of oil palm per hectare of oil palm, percentage of forest loss and a dummy variable of soil type (mineral only or mixed between mineral and peat) as independent variables. The coefficients of regression of the first two independent variables are highly significant while the third one is significant, with $R^2 = 0.67$. The regression model is:

$$y = 21.37 + 0.002\, x_1 - 0.27\, x_2 - 10.94\, x_3$$

where $y$ = carbon efficiency of a plantation; $x_1$ = NPV per hectare of oil palm; $x_2$ = percent of forest loss during plantation establishment; $x_3$ = dummy variable = 0 if plantation is of mineral soil only, 1, if it is mixed between mineral and peat.

## Conclusion and recommendations

Policies and/or best practices that promote the contribution of oil palm production to land-based, low emissions development should ideally devise a clear indicator linking land use and carbon efficiency. This would show the financial gain from each unit of greenhouse gas emissions occurring during the development and cultivation of oil palm in plantations.

Developing an indicator that is focused on the plantation is an effective way to show the links between emissions, drivers and actors, as it defines an operational scale attributable to a single actor rather than isolating emissions from any particular unit of commodity. Furthermore, to contribute to the sustainability of the broader landscape, ecosystem services beyond climate regulation should also be promoted (biodiversity maintenance and watershed protection, for example). Landscape configurations, such as promoting habitat corridors, riparian areas and forest patch mosaics, should also be considered.

In comparison with emissions savings that address the concerns of customers about the 'greenness' of a specific product, carbon efficiency addresses the local and national concerns of producers about wider issues of landscape sustainability. This makes maintaining carbon efficiency less restrictive than just attaining emissions savings requirements because it recognizes the need for a balance between planned development for economic growth, local sustainability and global responsibility. Oil palm establishment is one of the most important drivers of land conversion in Indonesia. Increasing the carbon efficiency of oil palm plantations and integrating it into land-use planning for low emissions development at a broader landscape[iii] will substantially contribute to reducing emissions while maintaining economic growth at the local level and eventually at the national level.

## Policy recommendations

- Establish a regulation that sets a minimum carbon-efficiency standard for existing and future oil palm plantations in order to reduce land pressure, promote intensification rather than expansion, and contribute to land-based, low emissions development. The sample plantations suggest USD20/t$CO_2$eq is a reasonable cut-off point between high and low carbon-efficiency at the plantation level.
- Improve plantation management to increase NPV per unit area of oil palm( for instance, through optimum use of fertilizer) in combination with reducing emissions from peat conversion and from highest stocked land cover.
- Avoid conversion to low NPV land uses that produce high emissions within the nucleus area.
- Set aside high conservation value areas for conservation as this can increase carbon efficiency and maintain other ecosystem services, such as biodiversity and hydrological functions.
- Promote ecological restoration in low productivity areas within the nucleus.

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