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Restoring ex mining area using *Pongamia pinnata* in Central Kalimantan: a reclamation program alternative base on bioenergy species

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Abstract. Malapari (*Pongamia pinnata* (L) Pierre) is an endemic species of Leguminosae from southeast Asia, Australia and Afrika. Malapari is one species alternative of Reclamation Program in PT Asmin Bara Bronang. The aims of this study are to know the growth and adaptation rate of Malapari in extrime area after charcoal mining and to introduce the malapari for a alternative species for reclamation program with bioenergy potential species. The research method used is the census method in areas planted with malapari at PT ABB which was observed from 2020 with parameters including malapari growth; survival rate; analysis of soil fertility; biodiversity and carbon estimate. The results showed that malapari growth on post-mining land was very rapid where within 4 years it increased in height by an average of 184,92cm with a diameter growth of 10.76 cm and a survival rate of 87,78%, above ground biomass 584,04kg (274,5kg carbon) with very good leaf growth in fresh dark green The condition of early soil fertility becomes increased after planting. The great hope in this program is that malapari can be an alternative species for post-coal mining forest restoration from local superior species of use that has the potential to be a bioenergy source.

1. Introduction

Energy demand is proportional to the demand for food needs in line with the increasing population growth in Indonesia[1,8].Energy needs for human life will increase along with the pace of urbanization and economic growth of the community. In time there will be an energy crisis because fossil fuel sources have been exhausted [2, 8]. Innovation is needed to move to renewable energy by utilizing restoration of degraded land, bioenergy can provide a potential alternative to meet the growing energy demand.

The Indonesian government has mandated increased production of renewable energy, including plant-based bioenergy (e.g., *Calophyllum inophyllum* L., *Elaeis guineensis* Jack.), to meet 23% of total energy use by 2025 [3, 8]. The expansion of bioenergy plantations can trigger massive forest clearing and compete with the likes of food production and biodiversity conservation. degraded and underutilized land has been identifified as a potential target area for bioenergy production [8].

One of the provinces in Indonesia that has an area of Central Kalimantan has one of the largest degraded land in Indonesia is Central Kalimantan which is 7.2 million hectares [8]. The highest contributing factors to forest degradation are cases of forest conversion for other types of land use, for example, agriculture and open-pit mining [9–11]. Forest fires have driven the escalation of degraded lands, including peatlands [11,12].

1.1 Malapari *(Pongamia pinnata)*

Pongamia pinnata syn. *Milettia pinnata* or known in Indonesia Malapari, is one of the species of the family Leguminosae has the advantage that its roots are able to symbiosis with nitrogen bacteria, it is expected to survive and increase soil fertility along with its growth. Malapari could be utilized to produce biofuel while restoring degraded land. Malapari is one of fast growing species with easy adaptation and produce bioenergy, precisely is bioavtur. Malapari is from. Andaman Island, Assam, Bangladesh, Bismarck Archipelago, Borneo, Caroline Is., China Southeast, Christmas I., East Himalaya, Fiji, Hainan, India, Japan, Jawa, Lesser Sunda Island, Malaya, Marianas, Myanmar, Nansei-shoto, New Caledonia, New Guinea, Nicobar Island, Northern Territory, Pakistan, Philippines, Queensland, Samoa, Sri Lanka, Sumatera, Taiwan, Thailand, Vanuatu, Vietnam, Wallis-Futuna Island, West Himalaya [6]. Here, we explore the potential of pongamia as a source of biofuel and for restoring degraded land in Indonesia. Pongamia occurs across Indonesia, in Sumatra, Java, Bali, West Nusa Tenggara and Maluku [17]. And now Australia is developing large malapari cultivation for land rehabilitation purposes and bioenergy purposes so that it is widely found there.

Malapari has many uses for the needs of human life, including chemical products, environmental utility for natural fertilizer, carbon product, and wind breaker in coastal area, fibre, forage, Medicine, toxins, wood and miscellaneous[12]. It grows to a height of 15–20 m and can grow in a range of environmental conditions. Its seeds can generate up to 40% crude oil by weight. It can help to restore degraded land and improve soil properties. Pongamia also provides wood, fodder, medicine, fertilizer and biogas. Therefore, as a multipurpose species, pongamia holds great potential to combat Indonesia's energy crisis and to restore much of the degraded land [17, 26].

1.2 Ex-mining Restoration

PT Asmin Bara Bronang (ABB) is a big coal mining company from the ASTRA Group located in Kapuas Regency, Central Kalimantan which has been operating for the last 10 years with high productivity and balanced environmental preservation efforts. The company has received the Blue Proper award for its environmental management system and this year it has increased to Green Proper which is considered superior in environmental management to remain sustainable [5].

Forest resources are multi-functional, because under standing forests contain other resources such as mining which also need to be considered because they are a fairly large contributor to the country's foreign exchange. With this condition, it is possible to carry out activities in forest areas for development outside the forestry sector, but with certain restrictions so that the function and ecosystem of the forest is not disturbed. In Law Number 41 of 1999, it is stated that the use of forest areas for mining purposes can be carried out through the issuance of a permit by the Minister and without changing the main function of the forest. In non-forestry development activities, there is a big possibility of changes and disruption of the forest ecosystem, especially in mining activities with an open system. Therefore, Law Number 41 Year 1999 also states that there is an obligation to reclaim and or rehabilitate forests according to the pattern set by the government. The reclamation area is a former mining area that has experienced degradation and deforestation, so human intervention is needed to restore or restore land and forest vegetation so that it can function optimally according to its designation.

Climate change felt to date needs to be mitigated by reducing carbon emissions and/or increasing carbon stock sequestration (11). Reducing carbon emissions can be done by: (a) maintaining existing carbon stocks by managing protected forests, controlling deforestation, implementing good silvicultural practices, preventing land degradation and improving the management of soil organic matter stocks, (b) serves in existing forests or reducing timber harvesting by developing forests with fast growing tree species. Plants are tasked with absorbing carbon in nature in the form of woody biomass, so the easiest way to increase carbon stocks is to plant and maintain trees. Of course, this activity must be supported by all levels of society so that the efforts made can achieve the expected goals [9].

The successfully of the reclamation program is assessed from several indicators, including periodic assessments of the increase in the species of flora and fauna or biodiversity that make up the area of the area. Mining reclamation is an obligation made by the Government in this case the party issuing business permits to mining companies to restore the condition of the former mining area to forest again as written in the Minister of Forestry Regulation Number: 146 / Kpts-II / 1999 regarding Guidelines for Reclamation of Former Inner Mining Forest Estate states that every mining and energy company has an obligation to carry out the reclamation of ex-mining land over borrowed forest areas. This aims to restore the condition of forest areas damaged by mining and energy business activities so that the forest areas in question can function again according to their designation. The forest here is not as long as it meets the requirements as an area that is overgrown with trees, but is far from the aspect of returning to its natural state, where the conditions that must be met are the fulfillment of the requirements for local superior plants planted in the area, restoring the hydrological function of the forest, and returning the forest to a habitat such as previously, or at least closer to the previous one, where forests are not just a producer of wood, but complex biodiversity including the area's carbon content.

Mining companies are required to carry out reclamation by making stages to organize, restore, and improve the quality of the environment and ecosystem so that they can function again according to their intended purpose (Regulation of the Minister of Energy and Mineral Resources Number 7 of 2014). Based on the Regulation of the Minister of Energy and Mineral Resources Number 7 of 2014 and Government Regulation Number 78 of 2010, ex-mining areas are required to carry out reclamation activities aimed at restoring the land condition as intended. The importance of reclamation activities in mining business means that the techniques in reclamation activities must be planned in a complex and consistent manner so that reclamation activities can achieve the desired targets. Environmental conservation efforts and sustainable environmental management by mining companies have a separate standard assessment at the Ministry of Mining and Energy and the Ministry of Environment and Forestry in the form of environmental awards. A good company is a company that manages sustainably and sustainably with certain conditions that are considered equal for the company to return the forest to its original state.

1.3 Why plant these species of bioenergy for post-mining land?

The rules in the Ministry of Environment and forestry that the requirements of types to be planted in mining reclamation are fast growing species plants, and endemic plants, but it does not hurt if the planted are the species that produce non-timber forest products such as food producers, renewable energy, honey, sap, resins, herbal medicine and so on. One of them is bioenergy-producing plants as it will be done. Initial trial planting has been conducted in 2019 for the former mining land of PT ABB and the results are very good as shown in the following Figure 2 [5].

Malapari has been grown as a commercial plant in several developed countries. The plant has proven to produce potential bioenergy as a substitute for plant-based and renewable avtur. It is necessary to conduct a study on the prospect of planting malapari on ex-mining land as an innovation for national energy security and utilizing areas with the species of producers of superior non-timber products including biooenergy.

2. Method

The research activity was carried out on restoration land (ex-mining) owned by PT ABB with a place height of 144 m above sea level at coordinates S 0^{0}59'23" E 114^{0}21'54". The parameters of the study include the annual growth of malapari with census analysis, soil analysis and the biodiversity of special reclamation areas planted with malapari. Soil analysis by BALITRA (Research Center of Peatswamp Land) of Ministery of Agriculture of Indonesia.

Observations were made for 4 years from the moment of planting in the planting path as many as six paths with a planting distance of 4x4m with inserting plants of *cassia siamea* and *Callophylum inophyllum*. The length of the path varies by path (1-6) with defferent number of

malapari trees adapted by slope of land. Figure 1 is the location of research in reclamation / restoration area in PT ABB.

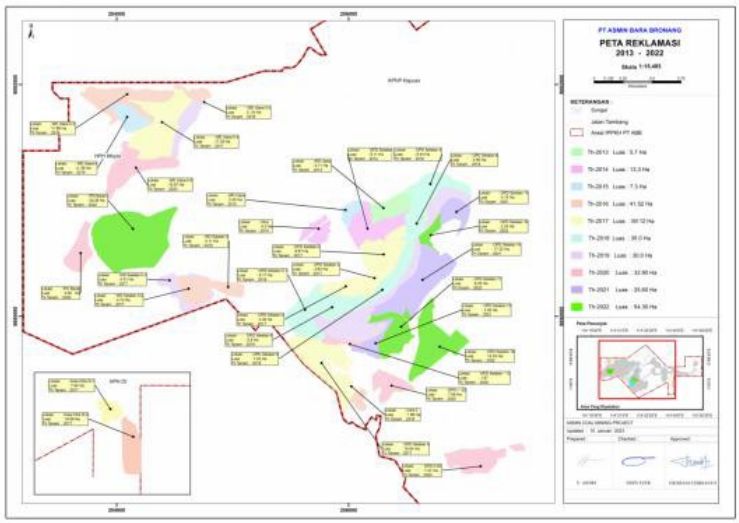
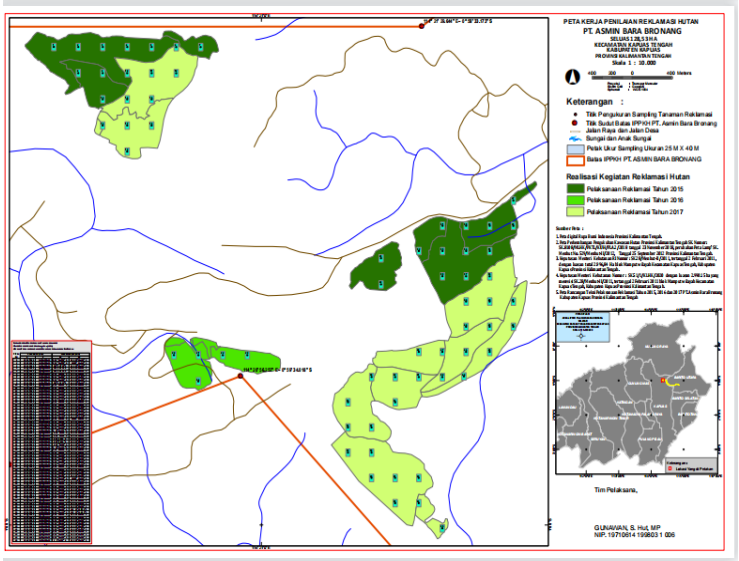


Figure 1. Reclamation Area of PT Asmin Bara Bronang in Baronang Village Kapuas District Central Kalimantan



Biodiversity analysis using biodiversity calculator tools from USAID Lestari and Michigan State University 2018 [10]. Biodiversity analysis [4; 5] :

a. Species richnes : The total number of species present in the sample assumes that the sample is representative of the population.
   S = number of species or taxon (plural: taxa)
b. Menhinick Index : the ratio of the number of taxa to the square root of the sample size D = s/(SQRT N)
   Where "s" = number of different species in the sample
   N = total number of individual organisms in the sample

c. Margalef Index : ratio of (S-1) more than LN of the total number of individuals (S-1)/ln(n)

d. Shannon Index : known as H'; A diversity index, taking into account the number of individuals as well as the number of taxa (different species). Varies from 0 for communities with only a single taxon to high values for communities with many taxa, each with multiple individuals. Shannon's index takes into account both the abundance and equitable distribution of species. The proportion of species i relative to the total number of species (pi) is calculated, and then multiplied by the natural algorithm of that proportion (lnpi). The resulting products are then summed across species, multiplied by -1.

$$H = -\sum_{i=1}^{s} pi \ \mathrm{In}\, pi$$

pi = proportion of the total number of individuals

e. Simpson Index: 1 - D where D is the Simposn Index which measures the probability that two randomly selected individuals from a sample will belong to the same species (or several categories other than species). There are two versions of the formula for calculating D. Both are acceptable, but consistently choose only one.

$$1 - \mathrm{D} = \sum (\frac{\mathrm{n}}{\mathrm{N}})^{2}$$

f. Eveness Index: Index values of 0 to 1 indicate equitable distribution or dominance of species diversity. It uses Shannon Index and Species Richness Value
Evenness = H'/lnS

Carbon analysis using carbon calculator tools from USAID Lestari and Michigan State University 2018 [9]. carbon analysis with census system that all of malapari trees are measuring with calculator carbon to detected the carbon increasing time by time of malapari growth.

3. Result and Discussion

PT Asmin Bara Bronang (ABB) carries out reclamation activities for former mines with various kinds of plants, one of which is the species of bioenergy-producing plants such as nyamplung, kaliandra, gamal and malapari. The selection of the species used is also based on previous species trial research [5,8,13,15]. The soil composition of the reclamation site in accordance with the regulations made has a top sol layer of only 50 cm for the surface and the inside of the subsoil and rock soil. The environmental conditions of the reclamation area are very extreme from temperature, very minimal soil fertility, dry without a water source and very minimal topsoil layer causes very large deaths in plants planted and needs special treatment (Figure 2).

Figure 2. Before and after restoration by Malapari

Malapari, which is a family of leguminosae, has the advantage that its roots are able to symbiosis with nitrogen bacteria, it is expected to survive and increase soil fertility along with its growth. Malapari is known to have high drought resistance because it usually grows on the coast area and it is one of the bioenergy-producing species that usually grows on the coast as a windbreaker plant as seen on the coastline of Sabang Island Aceh, turns out to be suitable for growing on ex-mining land that has extreme environmental conditions.

The extreme microclimate conditions, marginal soil layers and the adaptability of small plants on ex-mining land are major obstacles to reclamation activities in the region. Figure 2 below is the condition of the ex-coal mining land before and after carried out tree planting activities in the reclamation program shown in Figure 2 from the opened area to closed area with covercrop. The microclimate around the planting area becomes better as the plant growth time increases. Humidity of this area also becomes better. The temperature conditions at the site are very extreme high compared to forested land up to 35-40^{0}C. The area is very open there is no ground cover so that in the event of rain, the top soil layer will be leaching. The company came up with a solution to overcome this by planting a cover crop, but it takes a long time for this cover crop to grow to cover the soil surface.

The restoration soil layer consists of two layers, namely top soil with a depth of 50cm and the second layer is directly sub-fertile soil to the next depth with a homogeneous layer. The analysis for the initial study of restoration soils was as follows soils with pH H_2O : 5.47 pH N KCl : 4.39; Organic C content 0.28; total N amount 0.04 and available P_2O_5 content 4.48; Potential P 2.84; Potential K_2O 2.67; the presence of Cations can exchange K^+ : 0.07; Na^+ : 0.06; $Ca^>$ < 0.29; $Mg^>$ 0.06. Cation exchange capacity (KTK) : 2.26 with an alkaline saturation of 2.65. The texture of the soil with the ratio of sand : Dust : Clay in the form of 71 : 10 : 19. Electric charge power 0.044 mmho; Exchange sodium 0.00%; Al saturation : 24.34%. Survival rate for 4 years after planting is 87,78%. Mayority of malapari growth is with Obstacles caused by pest attacks from the class of ticks and lepodiptera larvae, and partly due to nutrient deficiencies. This does not cause death only to grow stagnant or very slow growth due to recovery, but others grow very quickly without interference from the surrounding environment. Growth for the first fourth years of malapari in the reclamation area can be seen in Charts 1 and 2 below :

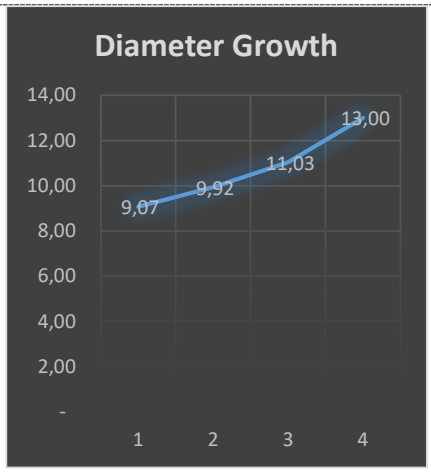


Chart 1. Diameter Growth (cm) in 4 years old

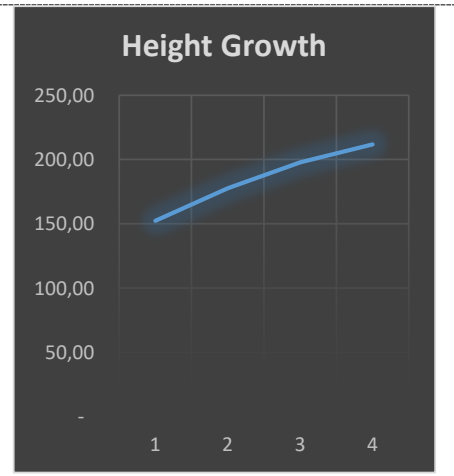


Chart 2. Height Growth (cm) in 4 years old

The values of biodiversity in restoration area with malapari give a positive impact, where there are some increasing values of biodiversity like species of trees, herbs and shrubs, and wildlife in 4 years monitoring. The wildlife found until this third year of observation included the addition of 5 species of birds at the reclamation site and there were a great stork species

that were protected, namely, several species of insects such as butterflies, moths, spiders, ants, grasshoppers, lizards and squirrels and local orchids has found in this area. All will improve as the region's malapari growth increases year after year (Figure 3 & 4). The species of plants that associated at the planting site are still mostly dominated by monocotyledonous grass species which shows that the area is still not suitable for planting species from the dicotyledonous group like malapari and must be given special treatment to become suitable.

Figure 3. Malapari

Figure 4. Bird nest in malapari plot

Likewise, the biodiversity index calculated using the Biodiversity calculator from year to year also increased, including for the carbon content produced from the growth of malapari. Table 1 is the result of the biodiversity analysis of the malapari reclamation area assessed in 2022 with the following data (7;10;11):

Table 1 Biodiversity analysis in reclamation area of malapari plot

	Trees > 5 cm DBH	Seedlings	Others Flora		
Species Richness	5	3	**Types**		**Num**
Richness Menhinick's Index	0,26	0,28	**Trees Plot**	**Liana**	**12**
Richness Margalef Index	0,68	0,42			
Shannon Index	1,24	0,49		**Shrub**	**18**
Simpson Index	0,67	0,26	**Seedling Plot**	**Fern**	**0**
Evenness Index	0,77	0,45		**Pandan**	**0**
	Johar	Malapari		**Small shrub**	**30**
	Sengon	Johar		**Herbs**	**36**
The Five Most Abundant Species (in terms of the total number of individuals)	Jabon	Sengon	**Pengumpulan Data**		
	Malapari		**Kuadran/ tree Plot (80x80m)**		**6**
	Sungkai		**Kuadran/Seedling Plot(2x2m)**		**6**

Table 2 Carbon Estimate in Malapari Plot

Jalur	AGB (kg)	Carbon (kg)	CO_2 (t)
1	126,12	59,28	0,22
2	97,67	45,90	0,17
3	72,51	34,08	0,12
4	106,94	50,26	0,18
5	103,16	48,48	0,18

6	77,65	36,49	0,13
Total	**584,04**	**274,50**	**1,01**

Malapari must also have a positive impact on increasing carbon content and carbon sequestration in the region as it grows and increases in a proportional time. Malapari give the increasing values of carbon time by time from 2020. From the calculation of the carbon calculator with census system, it is known that the addition of the amount of carbon in the malapari stand for Above Ground Biomass (AGB) 584,04 kg, with carbon content 274,5 kg and CO_2 1,01 ton in four year growth. Carbon estimates will tend to increase as plants grow over time as trees grow and plant growth resistance in extreme environments will become more adaptable to plant growth. It also includes elements of suitability assessment of other plant growth such as biodiversity, and soil quality will also improve over time if the area is maintained and cared for.

4. Conclusion

- The results showed that malapari growth on post-mining land was very rapid where within 3 years it increased in height by an average of 184,92 cm with a diameter growth of 10.76 cm and a survival rate of 87,78% with very good leaf growth conditions in dark green and fresh
- The addition of biodiversity in the area with a Simpson index of 0.67 for local tree species and found bird's nests in the malapari tree canopy, the condition of the land became more fertile where many dicotyledonous herbs began to grow evenly.
- The condition of early soil fertility becomes increased in fertility after planting malapari.
- The great hope in this program is that malapari can be an alternative species for post-coal mining forest restoration from local superior species of use that has the potential to be a bioenergy source.
- A potential carbon producer with the addition of carbon per year 2023 in the region of 274,5 kg of carbon with census data.

References

[1] IEA (International Energy Agency). 2015. *Indonesia 2015—Energy Policies beyond IEA Countries*; IEA: Paris, France.

[2] Firdaus, Y.; Mukhtasor; Suroso, A. 2011. *Analysis of an effect of oscillating part Transformation in vortex energy conversion using a numerical model.* J. Kelaut. Nas. **Volume 6**, 1–12.

[3] GOI (Government of Indonesia). PP No. 79 Thn 2014; GOI: Jakarta, Indonesia.

[4] Buckley, J. W. B., Capilla, B. R., Maimunah, S., Adul, Armadyanto, Boyd, N., Cheyne, S. M., Iwan, Husson, S. J., Santiano, Salahudin, Ferisa, A., Namaskari, N., Van Veen, F., & Harrison, M. E. (2018). *Biodiversity, forest structure and conservation importance of the Mungku Baru education forest, Rungan, Central Kalimantan, Indonesia.* Borneo Nature Foundation Internal Report.

[5] Internal report of Reclamation Project in PT Asmin Bara Bronang series 2020-2022.

[6] Kew Royal Botanical Garden. Plant of the World Online. Pongamia pinnata var. hannii | Plants of the World Online | Kew Science

[7] Maimunah, S., Capilla, B.R., and Harrizon, M., 2018. *Tree Diversity and Forest Composition of a Bornean Heath Forest Indonesia.* IOP Conference Series: Earth and Environmental Science. Hassanudin University. https://iopscience.iop.org/article/10.1088/1755-1315/270/1/012028

[8] Maimunah S., Syed Ajijur Rahman,*, Yusuf B. Samsudin, Yustina Artati, Trifosa Iin Simamora, Sarah Andini, Soo Min Lee and Himlal Baral, 2018. *Assessment of Suitability of Tree Species for Bioenergy Production on Burned and Degraded*

Peatlands in Central Kalimantan, Indonesia. Land journal. Published: October 7, 2018. https://www.mdpi.com/2073-445X/7/4/115 *Land* **2018**, *7*, 115; doi:10.3390

[9] Maimunah, S., Kessler, P.J.A., Indrioko, S., Naiem, M., and Samek, J.H., 2021. *Study of species associations in native habitats of the genus Dacrydium Lamb. (Podocarpaceae) in Central Kalimantan, Indonesia.* IOP Conference Series: Earth and Environmental Science. Hassanudin University.

[10] Maimunah, S., Kessler, P.J.A., Indrioko, S., and Naiem, M., 2022. *Natural distribution of the genus Dacrydium Lamb. (Podocarpaceae) in Central Kalimantan, Indonesia*. Biodiversitas https://doi.org/10.13057/biodiv/d230605

[11] UNEP Publication about Peat Restoration base on Bioenergy https://www.unenvironment.org/news-and-stories/story/unep-supports-project-restore-peatlands-indonesia

[12] Himlal B, Lee So min, Leksono B., 2022. Bioenergy and landscape restoration in Indonesia hhttps://www.cifor.org/knowledge/publication/8500

[13] https://iopscience.iop.org/article/10.1088/1755-1315/914/1/012009 Tamanu growth performance in different type of Degraded peatland in Central Kalimantan

[14] https://fao.zoom.us/rec/share/g8p35SB6ywFfyr5mg6Xhy3DzQ4dD_998GRf7e8nv47LeuoDAI6LJYdKdiKZElLA.Pk0vod9Pk-1pJTZa GPI in tittle Peatland restoration, bioenergy and community Case study in Barito Central Kalimatan

[15] "Restoration belongs to the community" - CIFOR Forests News"Restoration belongs to the community" - CIFOR Forests News

[16] https://www.researchgate.net/publication/337370189_Tropical_forest_and_peatland_conservation_in_Indonesia_Challenges_and_directions

[17] Baral, H.; Lee, S.M. 2016. *Sustainable Bioenergy Systems to Restore and Valorize Degraded Land*; CIFOR Brief No. 37. Center for International Forestry Research (CIFOR): Bogor, Indonesia.

[18] GGGI (Global Green Growth Institute). Renewable Energy Options in Kalimantan: A Green Growth Assessment. 2015. Available online: http://gggi.org/site/assets/uploads/2017/12/GGGI%E2%80%99sTechnical-Guidelines-on-Green-Energy-Development_dereje-senshaw2017.pdf (accessed on 27 March 2018).

[19] IEA (International Energy Agency). 2015. *Indonesia 2015—Energy Policies beyond IEA Countries*; IEA: Paris, France.

[20] Borchard, N.; Bulusu, M.; Hartwig, A.M.; Ulrich, M.; Lee, S.M.; Baral, H. 2018. Screening potential bioenergy production of tree species in degraded and marginal land in the tropics. *Forest.* **Volume 9**, 594. [CrossRef]

[21] Suwarno, A. 2016. *Optimising Land Use in Central Kalimantan Province, Indonesia: Modeling Ecosystem Benefifits and Land Use Dynamics.* Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands.

[23] Abood, S.A.; Lee, J.S.H.; Burivalova, Z.; Garcia-Ulloa, J.; Koh, L.P. 2015. *Relative contributions of the logging, fifiber, oil palm, and mining industries to forest loss in Indonesia*. Conserv. Lett. **Volume 8,** 58–67. [CrossRef]

[24] Medrilzam, M.; Dargusch, P.; Herbohn, J.; Smith, C. 2014. *The socio-ecological drivers of forest degradation in part of the tropical peatlands of Central Kalimantan, Indonesia.* Forestry **Volume 87**, 335–345. [CrossRef]

[25] Firdaus, Y.; Mukhtasor; Suroso, A. 2011. *Analysis of an effect of oscillating part transformation in vortex energy conversion using a numerical model. J. Kelaut. Nas.***Volume 6**, 1–12.

[26] Nijsen, M.; Edward, S.; Elke, S.; Detlef, P.V. 2012. *An evaluation of the global potential of bioenergy production on degraded lands. GCB Bioenergy* **2012**, *4*, 130–147. [CrossRef]

[27] Leksono B., E Windyarini, TM Hasnah, Fahruni, S Maimunah, Y Artati and H Baral, 2021. *Tamanu (Calophyllum inophyllum) growth performance on different types of degraded peatlands in Central Kalimantan IOP Conf. Ser.: Earth Environ. Sci.* **914** 012009

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