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FLORA DIVERSITY AND RESTORATION PLANNING FOR CRITICAL LAND IN STEAM-ELECTRIC POWER STATION ULUBELU AREAS

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ABSTRACT

Geothermal Power Plants are one of the applications of geothermal energy that can be utilized as a source of electricity. One of the geothermal power plants in Lampung is the Ulubelu PLTP, located in Tanggamus Regency. As an energy-producing agency, Ulubelu PLTP also contributes to the preservation of flora and fauna in its work area. This was demonstrated through the planting of various woody plants to add to the flora in the area. This study aimed to record the species of plants that existed, the abundance of various climatic and edaphic factors, as well as recommendations for the enhancement of flora diversity in the Ulubelu PLTP work area. The vegetation analysis method used to collect flora data was a census method divided into five observation transects. The dominant and codominant species found at the tree level were Acacia mangium and Erythrina variegate; at the pole level, Leucaena leucocephala and Toona sureni; at the sapling level, Gliricidia sepium and Syzygium myrtifolium, and at the ground-cover plant level, Imperata cylindrica and Mikania micrantha. In addition to commercial species, some species had the potential to be invasive in the Ulubelu PLTP area. The study also recommended that the plant species be restored to increase species diversity and vegetation density. The species recommended for restoration based on vegetation analysis data were those that have aesthetic value, those that produce fruit or flowers that could attract animals, protected species, or those that could be used for purposes beyond their wood.

Keywords: *Biodiversity; Flora; Geothermal; Restoration; Ulubelu*

INTRODUCTION

Indonesia has abundant geothermal resources that reach 40% of the total geothermal potential in the world (Gunawan et al., 2021). The potential of these resources is found in the western region of Indonesia because it is passed by the Ring of Fire which has high tectonic activity (Harefa & Harmok, 2021). According to Ritonga et al. (2020), 324 locations in Indonesia have the potential to build Geothermal Power Plants (PLTP) to increase the fulfilment of electrical energy nationally (Nurwahyudin & Harmoko, 2020). The use of geothermal energy is believed to be able to contribute to climate change mitigation. This is because this energy is a renewable energy source (Carlos et al., 2022) that produces low emissions (Aneke et al., 2011), which is around 75 g/kWh (International Energy Agency, 2023). Based on research conducted by Yousefi et al. (2019) the construction of a geothermal energy power plant can contribute to reducing CO_2 gas emissions, making it an environmentally friendly energy alternative compared to fossil energy.

Even though it has many benefits, the construction of these Geothermal Power Plants also causes loss of land cover and the environment. Geothermal exploration and exploitation activities are often carried out in conservation forest and protected forest area, resulting in loss of land cover corps and fragmentation of forest ecosystems. This can disrupt wildlife habitats, reduce the number of species, alter the composition of flora and fauna communities, and disappear endemic species (Víquez, 2006; Dhar et al., 2018a; Chen et al., 2019; Dhar, 2020). In addition, land clearing, road construction, and other infrastructure development can trigger soil erosion, increased surface run-off, and decrease soil fertility, which can ultimately lead to the formation of critical land around Geothermal Power Plants (Zhang et al., 2020).

One of the Geothermal Power Plants (in Indonesian as known as PLTP) in Indonesia is the Ulubelu PLTP located in Lampung Province. The construction of this PLTP is around a forest area that has the potential to cause deforestation. According to Jainuddin (2023), deforestation not only has an impact on reducing flora diversity but can also disrupt ecosystem function such as landscape change and global climate change that trigger natural disasters. The topography of the Ulubelu PLTP which is hilly and has an altitude of about 780 meters above sea level makes it a higher risk to surface run-off and hydrological systems if the vegetation is rare. A decrease in flora diversity is important to pay attention to because biodiversity has a role in supporting ecosystem functions, such as nutrient cycling, hydrology cycling, and carbon sequestration (Tarumingkeng, 2024). Previous studies have also said that flora diversity has an important role in maintaining ecosystem stability and resilience (Ikhsan et al., 2024). Ecosystems that have high flora diversity tend to have high resistance to environmental changes and external disturbances. Therefore, it is important to carry out restoration planning through revegetation to increase biodiversity and improve the ecological function of critical land. This study aims to examine the diversity of flora in critical land around PLTP and develop an ecology-based restoration strategy. By understanding the patterns of biodiversity in the region, it is hoped that an effective and sustainable restoration model can be proposed

METHOD

Research site

The research was conducted at Ulubelu PLTP, Tanggamus, Lampung Province, covering an area of approximately 11 hectares. Data collection took place from September 7 to 14, 2024. At the research site, flora observations were conducted along five transect lines to conduct vegetation analysis. On each transect line, all vegetation species growing on the land were counted in full. The distribution of flora observation lines at the research site is presented in Figure 1.

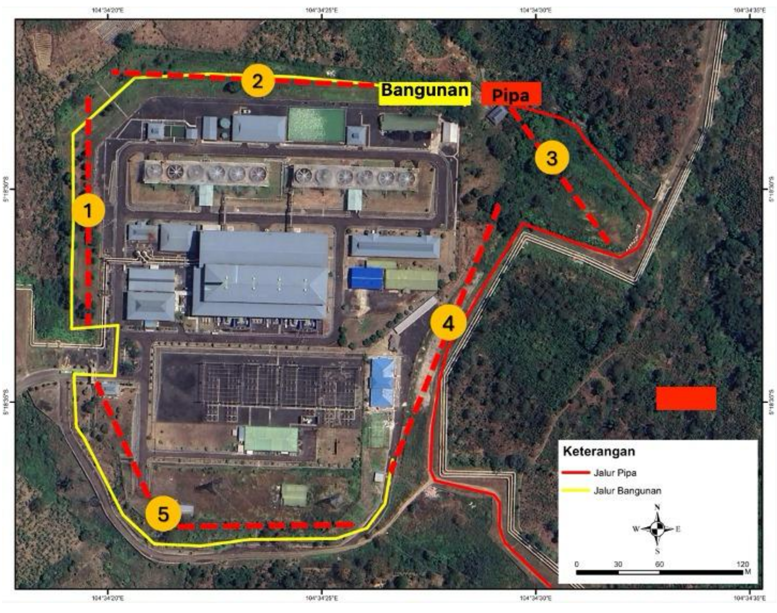


Figure 1. Distribution of flora observation lines at Ulubelu PLTP

Environment condition

Environmental conditions were observed along each research transect. The observed ecological parameters included air temperature, relative humidity, solar intensity, and soil pH. Ecological data were collected three times a day (morning, afternoon, and evening) at each transect. Air temperature was measured using a data logger over a four-day observation period.

Vegetation analysis

Vegetation data were collected using the census method at the pole and tree stages. The census method involves a full inventory of all poles and trees present at the research site. The pole stage refers to plant individuals with a height exceeding 150 cm and a trunk diameter ranging from 10 to 20 cm, while the tree stage includes individuals with a trunk diameter greater than 20 cm. For these stages, observations included total height, branch-free height, diameter at breast height (DBH), geographic coordinates, and species identification.

For the seedling and ground vegetation stages, data were collected using a sampling method. A seedling is defined as a young tree that has recently germinated from a seed, typically less than 1,5 meters tall (Kusmana et al., 2022). Ground vegetation refers to all understory plants excluding tree saplings, such as grasses, herbs, shrubs, and ferns (Kusmana et al., 2022). Observations of seedlings and ground vegetation were conducted within 2 m x 2 m plots. Each transect line contained one observation plot at the seedling level, and the number of individuals per species and their identification were recorded.

In this study, vegetation profiles were created using Spatially Explicit Individual based Forest Simulator (SExI-FS) (Harja & Vincent, 2008) and species diversity indices were analyzed using the PAST4 software, a statistical tool commonly used for ecological data analysis (Hammer, Harper, & Ryan, 2001). The analyses conducted included dominance analysis, Shannon diversity index, evenness index, species richness index, Chao1, ACE, and real difference value test (t-test). Additional vegetation analyses were performed for seedlings, saplings, poles, and trees data to determine the Important Value Index (IVI), species richness index (R), diversity index (H'), evenness index (E), and dominance index (C) with the following formula (Soerianegara & Indrawan, 2005):

Density (De) $= \frac{Number\ of\ individuals\ per\ species}{Sample\ plot\ area}$

Relative Density (RD) $= \frac{Density\ of\ a\ species}{Density\ of\ all\ species} \times\ 100\%$

Frequency (Fq) $= \frac{Number\ of\ plots\ found\ of\ a\ species}{Number\ of\ plots}$

Relative Frequency (RF) $= \frac{Frequency\ of\ a\ species}{Frequency\ of\ all\ species} \times\ 100\%$

Dominance (Do) $= \frac{The\ basic\ area\ of\ a\ species}{Sample\ plot\ area}$

Relative Dominance (RDo) $= \frac{Dominance\ of\ a\ species}{Dominance\ of\ all\ species} \times 100\%$

IVI = RD + RF (seedling-ground vegetation and sapling stage)
IVI = RD + RF + RDo (pole and tree stage)

Diversity index (H') $= -\Sigma Pi.ln\ ln\ (Pi)\ =\ -\Sigma \left(\frac{ni}{N}\right) ln\ ln\ \left(\frac{ni}{N}\right)$ **(Shannon & Weaver, 1949)**

Annotation:
H' = Diversity index (Shannon-Wiener)

ni = Number of individuals to-i
N = Number of Individual
Evenness index ($E) = \frac{H'}{ln\ s}$ **(Pielou, 1966)**
Annotation:
E = Evenness index
H' = Diversity index (Shannon-Wiener)
s = Number of species

Species Richness index Margalef ($R) = \frac{S-1}{ln\ N}$ **(Margalef, 1958)**
Annotation:
R = Species Richness Index Margalef
S = Number of species
N = Number of Individual

RESULTS AND DISCUSSION

Environment condition

The results of the temperature and humidity measurements indicated that the average temperature at the research site was 22.2 °C, while the relative humidity of 89.4% (see **Figure 2**). Situated at the foothills of a mountain, Ulubelu experiences notable temperature fluctuations, ranging from a minimum of 18.6°C to a high of 27.6 °C.

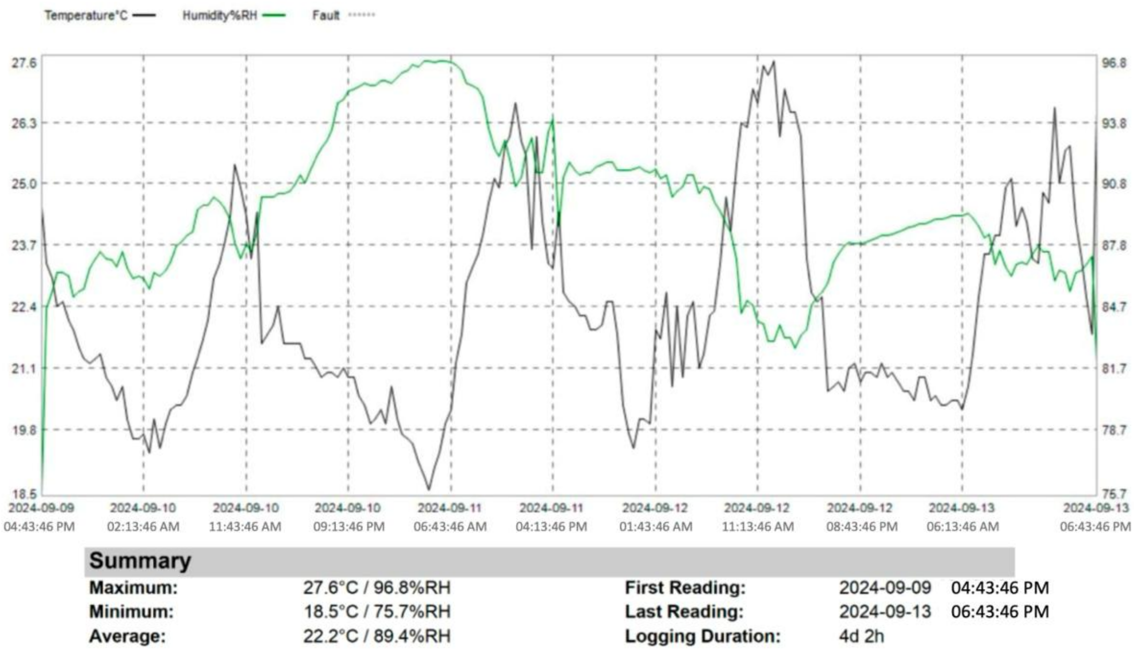


Figure 2. Temperature and humidity of Ulubelu PLTP

The temperature and humidity data shown in Figure 2 indicate an inverse relationship: as temperature decreases, humidity increases. However, this pattern does not always occur in natural conditions, as both temperature and humidity are also influenced by vegetation and cloud conditions in the area. The observed temperature fluctuations suggest limited vegetation cover. Vegetation plays a crucial role in absorbing solar radiation, with some of the absorbed energy transferred to the soil. In areas with sparse vegetation, heat is absorbed directly by the soil during the day and rapidly released at night, leading to significant temperature variation between day and night. This occurs because soil tends to absorb and release heat more readily compared to vegetated surfaces.

The operational area of the Ulubelu Geothermal Power Plant (PLTP) was described based on observations along five transect lines. Line transect 1 was dominated by pine trees (*Pinus* spp.) with sparse undergrowth. This was likely due to the slow decomposition of pine leaf litter, which inhibits the growth of other plant species (Kimura, Sato, & Kato-Noguchi, 2015). In addition to pine, this line transect also featured mahogany (*Swietenia* spp.), acacia (*Acacia mangium*), and several Multipurpose Tree Species (MPTS) such as guavas (*Syzygium malaccensis)*, mangoes (*Mangifera indica*), river tamarind (*Leucaena leucocephala)*, and Spanish cherry (*Mimusops elengi*). Soil moisture was very low on sweltering days, around 10%, with a land slope ranging from 35º to 50º. Line transect 2 contained no large trees. The area was dominated by shrubs, with a small path of gamal (*Gliricidia sepium*) present. This line transect was located in an open area with approximately 10% soil moisture and a land slope of 35º to 50º. Line transect 3 bordered a small stream, which contributed to lower temperatures and higher humidity. Soil moisture reached 40% with a neutral pH of 7.3. Several tree species were recorded, especially acacia and sonokeling (*Dalbergia latifolia*). The canopy cover was denser, and species diversity was higher compared to the other transect. The slope of the land varied from 13º to 40º. Line transect 4 covered a very narrow area. The boundary wall of PLN was less than 1 m from the pipeline. This line was directly privately owned land used for coffee plantations managed under an agroforestry system, with a gently sloping topography (<10º). Few trees were found along this line transect, but some individuals had relatively large diameters. Line transect 5 was located adjacent to an asphalt road. The dominant tree species was dadap (*Erythrina variegata*), commonly used as a roadside plant. In the sloped area near the substation wall, many gamal (*G. sepium*) and banana plants (*Musa* spp.) were found. Several bamboo clumps were also observed along the wall. MPTS along this line transect included guava (*Psidium guajava)*, jackfruit (*Artocarpus heterophyllus*), cempedak (*A. integer*), and mango (*M. indica*). In the sloping area directly adjacent to the wall, vegetation cover was low, and grasses were dominant.

Vegetation Diversity

The results of the vegetation survey revealed a total of 85 species belonging to 39 plant families. These species were categorized into four growth stages: ground vegetation and seedlings, saplings, poles, and trees. The composition of families and the number of species in each growth stage are presented in Figure 3.

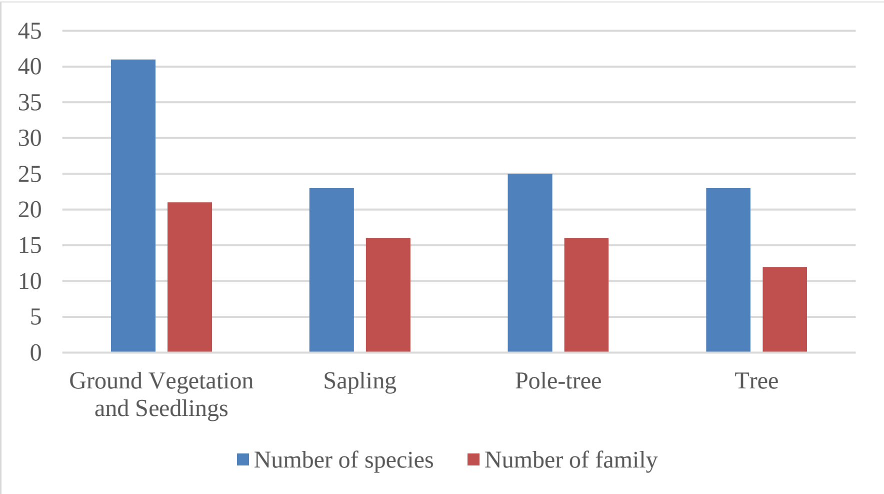


Figure 3. Family composition and number of species at each growth stage

Based on the calculation results, vegetation at the sapling, pole, and tree levels was dominated by species from the Fabaceae family. Fabaceae species record at the Ulubelu PLTP included *A. mangium, C. callothyrsus, E. variegata, D. latifolia, L. leucocephala, Samanea saman, G. sepium,* and *Falcataria moluccana*. Woody plant species were more diverse across the different growth stages. A total of 23 species were identified at these stages, with the majority classified as Multipurpose Tree Species (MPTS). MPTS are tree species valued not only for their wood and ecological functions but also for non-timber products such as fruits, such as *P. guajava, S. malaccensis, Persea americana, A. heterophyllus, M. indica, Citrus reticulata, Morus alba, Pometia pinnata,* and *Cinnamomum burmannii* (Bhat & Verma, 2002). These species have the potential to develop into pole and tree stages. At the pole stage, the vegetation consists of both woody and MPTS species, whereas at the tree stage, woody species are more dominant. For further clarity, the diversity data are presented in the following table.

Table 1. The species of plants found in the Ulubelu PLTP

No	Local Name	Scientific Name	Family	SGV	S	P	T	Total
1	Akar wangi	*Polygala paniculata*	Polygalaceae	2				**2**
2	Akasia	*Acacia mangium*	Fabaceae	1		5	37	**43**
3	Alpukat	*Persea americana*	Lauraceae		2	2		**4**
4	Antap-antapan	*Centrosema pubescens*	Fabaceae	1				**1**
5	Anting putri	*Wrightia religiosa*	Apocynaceae		2			**2**
6	Ara sungsang	*Asystasia gangetica*	Acanthaceae	3				**3**
7	Araucaria	*Araucaria cunninghamii*	Araucariaceae		1			**1**
8	Babandotan	*Ageratum conyzoides*	Asteraceae	1				**1**
9	Bayur	*Pterospermum celebicum*	Malvaceae				1	**1**
10	Bungur	*Lagerstroemia speciosa*	Lythraceae		1			**1**
11	Cemara	*Callitris preissii*	Cupressaceae		3	15	2	**20**
12	Cemara laut	*Casuarina equisetifolia*	Casuarinaceae				2	**2**
13	Cempedak	*Artocarpus integer*	Moraceae			3		**3**
14	Climbing hempvine	*Mikania scandes*	Asteraceae	1				**1**
15	Cuphea	*Cuphea elliptica*	Lythraceae	1				**1**
16	Dadap	*Erythrina variegata*	Fabaceae		3	7	15	**25**
17	Daun merah	-	Fabaceae	1				**1**
18	Durian	*Durio zibethinus*	Bombacaceae			1		**1**
19	Gajah mini	*Anoxopus compressus*	Poaceae	1				**1**
20	Gamal	*Gliricidia sepium*	Fabaceae		80	1	1	**82**
21	Glodokan tiang	*Polyalthia longifoli*	Annonaceae		8	1		**9**
22	Harendong	*Melastoma malabathricum*	Melastomaceae	2				**2**
23	Harendong bulu	*Clidemia hirta*	Melastomaceae	2				**2**
24	Ilalang	*Imperata cylindrica*	Poaceae	2				**2**
25	Jalantir	*Conyza sumatrensis*	Asteraceae	1				**1**
26	Jambu biji	*Psidium guajava*	Myrtaceae	1	12			**13**
27	Jambu Bol	*Syzygium malaccensis*	Myrtaceae			2		**2**
28	Jampang kawat	*Spermacoce ocymifolia*	Rubiaceae	1				**1**
29	Jeluang	*Broussonetia papyrifera*	Moraceae	1				**1**

No	Local Name	Scientific Name	Family	SGV	S	P	T	Total
30	Jeruk	*Citrus reticulata*	Rutaceae		5			**5**
31	Johar	*Cassia sp.*	Fabaceae				1	**1**
32	Kacang lentil	*Vicia lens*	Fabaceae	1				**1**
33	Kaliandra	*Calliandra calothyrsus*	Fabaceae	1				**1**
34	Kapuk	*Ceiba petandra*	Malvaceae				2	**2**
35	Kayu manis	*Cinnamomum burmannii*	Lauraceae		2			**2**
36	Kemiri	*Aleurites moluccanus*	Euphorbiaceae				1	**1**
37	Ketapang kencana	*Terminalia mantally*	Combretaceae			3		**3**
38	Kopasanda	*Chromolaena odorata*	Asteraceae	3				**3**
39	Kopi	*Coffea arabica*	Rubiaceae	1				**1**
40	Krei payung	*Filicium decipiens*	Sapindaceae		5			**5**
41	Krei Payung	*Filicium decipiens*	Sapindaceae			3	2	**5**
42	Lamtoro merah	*Leucaena leucocephala*	Fabaceae			9	7	**16**
43	Lempuyang	*Zingiber zerumbet*	Zingiberaceae	1				**1**
44	Mahoni	*Swietenia mahagoni*	Meliaceae		3	1	1	**5**
45	Mangga	*Mangifera indica*	Anacardiaceae		5	10	4	**19**
46	Matoa	*Pometia pinnata*	Sapindaceae		1			**1**
47	Mengkirai	*Trema orientalis*	Cannabaceae				2	**2**
48	Mindi	*Melia azedarach*	Meliaceae			2	3	**5**
49	Miscanthus	*Miscanthus sinensis*	Poaceae	1				**1**
50	Murbei	*Morus alba*	Moraceae		10			**10**
51	Nangka	*Artocarpus heterophyllus*	Moraceae		1	2		**3**
52	Paku kijang	*Athyrium sorzogonense*	Woodciaceae	3				**3**
53	Paku sayur	*Diplazium esculentum*	Athyriaceae	1				**1**
54	Pecut kuda	*Stachytarpheta jamaicensis*	Verbenaceae	1				**1**
55	Pegagan	*Centella asiatica*	Apiaceae	1				**1**
56	Pimpernel kuning	*Lysimachia nemorum*	Primulaceae	1				**1**
57	Pinang	*Areca catechu*	Arecaceae		2			**2**
58	Pinus	*Pinus merkusii*	Pinaceae			4	20	**24**
59	Pisang	*Musa sp.*	Musaceae		50			**50**
60	Pucuk merah	*Syzygium myrtifolium*	Myrtaceae		20	2		**22**
61	Putri malu	*Mimosa pudica*	Fabaceae	2				**2**
62	Rumput bebesan	*Oplismenus burmanni*	Poaceae	1				**1**
63	Rumput capitata	*Hyptis capitata*	Lamiaceae	1				**1**
64	Rumput Jari	*Digitaria sanguinalis*	Poaceae	1				**1**
65	Rumput kancing palsu halus	*Spermacoce glabra*	Poaceae	1				**1**
66	Rumput potong padi	*Leersia oryzoides*	Poaceae	1				**1**
67	Rumput roset heller	*Dichanthelium oligosanthes*	Poaceae	1				**1**
68	Samama	*Samama cadamba*	Rubiaceae			1	3	**4**

No	Local Name	Scientific Name	Family	SGV	S	P	T	Total
69	Sembung rambat	*Mikania micrantha*	Asteraceae	4				**4**
70	Sengon	*Falcataria falcata*	Fabaceae				8	**8**
71	Sintrong	*Crassocephalum crepidioides*	Asteraceae	1				**1**
72	Sirih hutan	*Piper aduncum*	Piperaceae	1				**1**
73	Sonokeling	*Dalbergia latifolia*	Fabaceae		2	9	12	**23**
74	Stinkwood	*Piscidia carthagenensis*	Fabaceae	1				**1**
75	Sukun	*Artocarpus communis*	Moraceae			1		**1**
76	Sungkai	*Peronema canescens*	Lamiaceae		2			**2**
77	Suren	*Toona sureni*	Meliaceae			9	3	**12**
78	Tabebuya	*Tabebuia aurea*	Bignoniaceae			1		**1**
79	Tali jiwo	*Kopsia arborea*	Apocynaceae		2			**2**
80	Tanjung	*Mimusop elengi*	Sapotaceae		5			**5**
81	Tanjung	*Mimusops elengi*	Sapotaceae			6	1	**7**
82	Teki ladang	*Cyperus rotundus*	Cyperaceae	1				**1**
83	Trembesi	*Samanea saman*	Fabaceae			1	4	**5**
84	Waru	*Hibiscus tiliaceus*	Malvaceae	1		4	10	**15**
85	Wavyleaf basketgrass	*Oplismenus undulatifolius*	Poaceae	1				**1**

Annotation: SGV (Seedling and ground vegetation), S (Sapling), P (Pole), T (Tree)

Vegetation at the seedling and undergrowth levels was dominated by species from the Poaceae family. Poaceae, a family of grasses, is well adapted to open, marginal, and frequently disturbed habitats (Peterson, 2013). Portion of the Ulubelu PLTP area consist of open land, which supports the proliferation of various Poaceae species. The higher plant seedlings identified included one individual each of *A. mangium*, *P. guajava*, and *H. tiliaceus*. The limited number of seedlings observed is likely due to routine maintenance activities within the Ulubelu PLTP area, as well as land cover management and planting arrangements designed to prevent overlapping vegetation that could interfere with operational activities.

Plant species commonly found across multiple growth stages (from sapling to trees) included *D. latifolia, S. mahagoni, M. indica*., *E. variegata*, and *Callitris preissii,* indicating strong ecological persistence and adaptability. Based on CITES 2016, *D. latifolia* was listed in Appendix 2 and by the end of 2020, *D. latifolia* is classified as Vulnerable under the IUCN A1cd criteria (Manohara *et al.* 2025). This species is naturally distributed across Indonesia and is widely cultivated in Lampung Province for timber. However, due to its high commercial value, *D. latifolia* is often subject to illegal logging. Other factors contributing to its decline include deforestation and the replacement of forest vegetation with fruit-bearing or other non-timber-producing species. Therefore, the presence of *D. latifolia* in the Ulubelu PLTP area plays an important role in supporting the conservation and sustainability of this valuable species.

The conservation status of flora identified at the research site was assessed based on both national and international regulations. Information on conservation status is essential to understand the level of threat and protection required for each species. The national The Conservation status was evaluated using the list provided in Government Regulation No. 106 of 2018 concerning Protected Plant and Animal Species in Indonesia. Additionally, international conservation status was determined based on the Red List of the International Union for Conservation of Nature (IUCN) and the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

The results of the analysis based on the Minister of Environment and Forestry Regulation (PermenLHK) No. P.106/2018 indicated that none of the recorded plant species are currently protected under Indonesian law. According to the IUCN Red List, two species, *D. latifolia* (sonokeling) and *P. merkusii* (pine) are categorized as Vulnerable (VU), while one species, *S. mahagoni* (mahogany), is classified as Near Threatened (NT). Based on the CITES Appendices, two species, *D. latifolia* and *S. mahagoni*, are listed in Appendix II. Species in CITES Appendix II are not necessarily threatened with extinction but may become so unless trade is closely controlled.

At each stage of plant growth, dominant and codominant species were identified. The dominant species is defined as the one with the highest Importance Value Index (IVI) within a given growth stage. The IVI reflects the ecological role and relative importance of a species within a plant community. A high IVI value indicates dominance, which may suggest that the species is highly adaptive or potentially invasive. The dominant and codominant plant species identified at each growth stage are presented in Table 2.

Table 2. The number of dominant and codominant species at each stage

Growth Stage	Species	De (ind/ha)	Do (m^2/ha)	Fq	IVI (%)
Seedling and Ground Vegetation	1. *Imperata cylindrica*	1100	-	0,40	22,68
	2. *Mikania micrantha*	500	-	0,80	15,93
Sapling	1. *Gliricidia sepium*	16	-	1,00	59,33
	2. *Syzygium myrtifolium*	4	-	0,20	13,61
Pole	1. *Leucaena leucocephala*	9	0,12	0,67	28,65
	2. *Toona sureni*	9	0,15	0,33	25,18
Tree	1. *Acacia mangium*	7,40	4,33	0,67	73,67
	2. *Erythrina variegata*	3,00	1,36	0,50	30,67

Annotation: De (density), Do (Dominance), Fq (Frequency), IVI (Importance Value Index)

Based on Table 2, the dominant and codominant species identified at each growth stage differed. This dominance value reflects the abundance of a species within the community, its size, and the evenness of its distribution in the ecosystem. A Species that is dominant at one growth stage is not necessarily dominant at other stages. The variation in dominant and codominant species across growth stages suggests that regeneration among species is inconsistent and may not be occurring uniformly across all plant species.

Diversity Index, Evenness Index, Species Wealth Index

The diversity index (H'), evenness index (E), and species richness index (R) were calculated only for vegetation at the seedling and undergrowth levels. Observations recorded 41 species and 231 individual plants within these growth stages. The calculated Shannon Diversity Index (H′) was 2.997. According to Magurran (2004), this value falls within the moderate diversity category (1 ≤ H′ ≤ 3). A diversity index in this range suggests a relatively stable ecological balance in the observed area. The values of the diversity, evenness, and species richness indices are presented in Table 3.

Table 3. The diversity index, evenness index, and species wealth index in Ulubelu PLTP

Indeks	Index Value
Number of species	41
Number of Individual	231
Diversity Index (H')	2,997
Evenness Index (E)	0,807

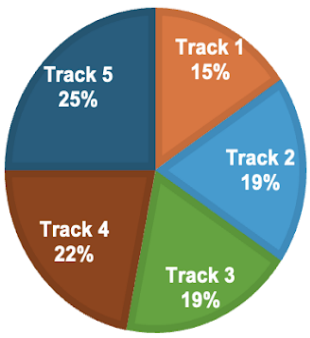
Species Wealth Index (R)	36,439

The more species of vegetation in an area, the higher the diversity index value. Homogeneous communities have a lower species diversity index compared to heterogeneous stand communities. Communities that are constantly exposed to disturbances such as fires, floods, and human intervention have a lower index of species diversity compared to communities that reach a climax (Setiadi, 2005).

The value of the species Evenness Index (E) in seedling vegetation and undergrowth is 0.807 (high category). The value of the Species Wealth Index (R) in seedling and undergrowth vegetation is 36,439 (high category). The value of E index and H index are also supported by the condition of the vegetation habitat in the Ulubelu PLTP area which has a humidity of 65 – 75% and a temperature of 22 – 26 °C. This is by the results of studies that show that the optimal temperature for the photosynthesis process in tropical forests is 23.7 – 28.1 °C (Tan et al., 2017). Relative humidity is an important parameter for plant growth as it affects the water balance and photosynthesis processes in plants (Chia & Lim, 2022).

Tree Distribution and Profile Diagram

The results of the analysis of tree distribution at the sapling, pole, and tree growth stages indicate that the distribution of trees within the Ulubelu PLTP area is uneven. As shown in Figure 4, tree species were most frequently found along Line 4, accounting for 22% of the total distribution. This transect represents the flattest terrain among all observation lines and is adjacent to a coffee plantation managed under an agroforestry system, which likely contributes to its higher vegetation cover.



Track 1	Track 2	Track 3	Track 4	Track 5
P. merkusii	*D. latifolia*	*C. petandra*	*H. tiliaceus*	*E. variegata*
L. leucocephala	*L. leucocephala*	*E. variegata*	*T. sureni*	*D. latifolia*
S. mahagoni	*A. mangium*	*A. moluccanus*	*M. azedarach*	*A. mangium*
A. mangium	*F. falcata*	*P. celebicum*	*G. sepium*	*M. indica*
F. falcata	*S. saman*	*A. mangium*	*C. petandra*	*M. elengi*
	Cassia sp.	*D. latifolia*	*S. cadamba*	*F. decipiens*
			T. orientalis	*C. preissii*
				C. equisetifolia

Figure 4. Tree distribution in line observation

Based on the observations, *Acacia mangium* was found to be evenly distributed across all growth stages and observation lines, indicating its high adaptability. This condition warrants attention, as *A. mangium* is considered an invasive species; therefore, its population should be controlled to allow other plant saplings to establish and compete within the community.

A portion of the Ulubelu PLTP area consists of open land. This condition is illustrated by tree profile diagrams constructed for Line 1 (western part of the Ulubelu PLTP) and Line Transect 2 (northern part). These diagrams provide insights into the successional stage of vegetation, particularly regarding the shade tolerance of various tree species (Puettmann et al., 2009). Profile diagrams were used to identify forest canopy stratification (Baker & Wilson, 2000). The vertical profile diagram illustrated the stratification of vegetation within the forests. Both horizontal and vertical profile diagrams were presented in Figure 5 and Figure 6.

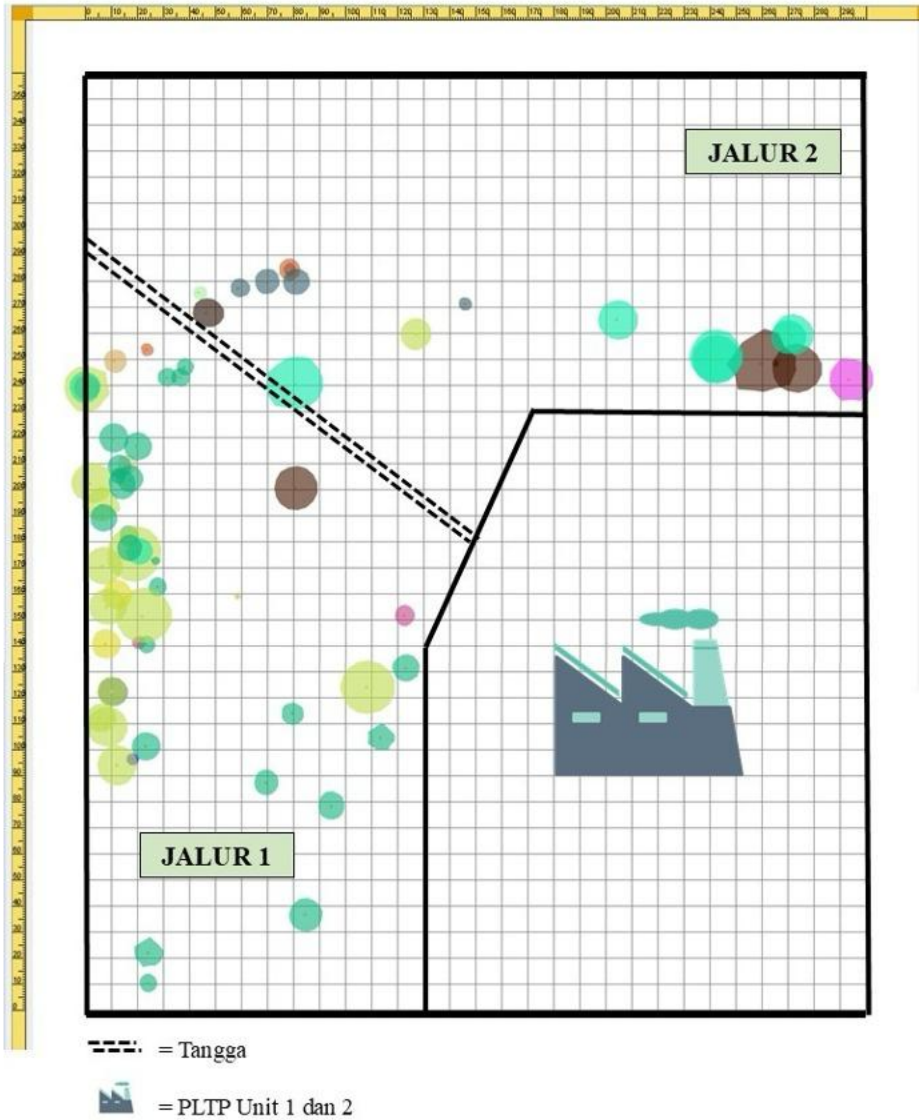


Figure 5. Horizontal Tree Profile Diagram on Line 1 and Line 2

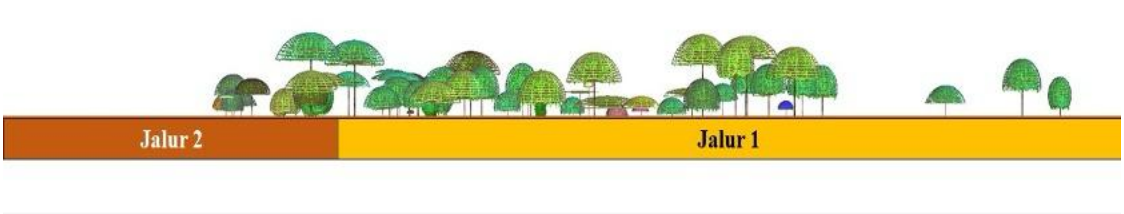


Figure 6. Vertical Tree Profile Diagram on Line 1 and Line 2

Figures 5 and 6 illustrate the uneven distribution of tree vegetation along Lines 1 and 2. On Line 1, tree vegetation tended to cluster along one edge of the transect, while tree presence on Plot 2 was sparse. Vegetation on Plot 1 was dominated by *P. merkusii* and *A. mangium*. Line 2 is dominated by tree vegetation with *L. leucochepala* and *S. saman* species. This unevenness was caused because plot 2 conditions were close to the steam pipeline which affected the environmental conditions. The existing pipeline released toxin air pollutants such as H_2S and SO_2 and increased soil temperature causing plant stressed or death (Bošnjaković, Stojkov, & Jurjević, 2019).

Based on the observation results, the tree planting distance in both plots is irregular. The recommended *P. merkusii* planting distance in a mixed planting system is 3 m x 4 m or 3 m x 3 m (Anjarsari et al., 2022). The planting distance of *A. mangium* should be 3 m x 3 m (Aminah et al., 2014). The planting distance of *S. saman* should be 10 m x 10 m (Nurgiantoro et al., 2022) and the planting distance of *L. leucochepala* should be 5 m x 5 m to 8 m x 8 m (Kalang, 2014).

Invasive Alien Species (IAS)

Invasive Alien Species (IAS) refer to non-native species that are introduced into an ecosystem, either intentionally or unintentionally, and possess the capacity to cause ecological disruption, economic losses, and broad impacts on habitat structure and function (Setyawati et al., 2015). The term IAS encompasses both alien (non-native) species and invasive species, which may or may not be native, but have the potential to proliferate and dominate (CBD-UNEP, 2014).

IAS plant species are introduced from outside their native range and can pose serious threats to ecosystems, biodiversity, socioeconomic systems, and human health. These impacts may occur at multiple levels, including the ecosystem, population, and genetic levels (CBD-UNEP, 2014). IAS can lead to the extinction of native species due to their capacity to dominate various ecological niches in the absence of natural predators or competitors (Radosevich et al., 2007). Environmental conditions and the lack of natural enemies often drive the aggressive spread of these species, resulting in significant ecological and economic consequences. Among the 85 plant species identified in the study area, 23 species were classified as invasive alien species (Setyawati et al., 2015). The list of identified IAS is presented in **Table 4.**

Table 4. Invasive Alien Species (IAS) in Ulubelu PLTP

No	Local name	Scientific name	Family
1	Akar wangi	*Polygala paniculata*	*Polygalaceae*
2	Akasia	*Acacia mangium*	*Fabaceae*
3	Antap-antapan	*Centrosema pubescens*	*Fabaceae*
4	Ara sungsang	*Asystasia gangetica*	*Acanthaceae*
5	Babandotan	*Ageratum conyzoides*	*Asteraceae*
6	Baret	*Mimosa pigra*	*Fabaceae*
7	Climbing hempvine	*Mikania scandes*	*Asteraceae*
8	Harendong	*Melastoma malabathricum*	*Melastomaceae*
9	Harendong bulu	*Clidemia hirta*	*Melastomaceae*
10	Ilalang	*Imperata cylindrica*	*Poaceae*
11	Jalantir	*Conyza sumatrensis*	*Asteraceae*
12	Jambu biji	*Psidium guajava*	*Myrtaceae*
13	Jampang kawat	*Spermacoce ocymifolia*	*Rubiaceae*
14	Kaliandra	*Calliandra calothyrsus*	*Fabaceae*
15	Kopasanda	*Chromolaena odorata*	*Asteraceae*
16	Lamtoro merah	*Leucaena leucocephala*	Fabaceae
17	Pegagan	*Centella asiatica*	*Apiaceae*
18	Putri malu	*Mimosa pudica*	*Fabaceae*
19	Rumput capitata	*Hyptis capitata*	*Lamiaceae*
20	Sembung rambat	*Mikania micrantha*	*Asteraceae*
21	Sintrong	*Crassocephalum crepidioides*	*Asteraceae*
22	Sirih hutan	*Piper aduncum*	*Piperaceae*
23	Teki ladang	*Cyperus rotundus*	*Cyperaceae*

Among the identified species, several were commonly found at the research site, including *A. mangium*, *Mimosa pigra*, *C. calothyrsus*, *Melastoma malabathricum*, and *Imperata cylindrica*. *A. mangium* was recorded in the Ulubelu PLTP area with 37 individual trees with an IVI of 78.58%, the highest among all tree species observed in the area. This indicates the dominant role of *A. mangium* in the plant community within this ecosystem. Despite being categorized as an Invasive Alien Species (IAS), *A. mangium* has notable economic value, as it is commonly used to produce particleboard, pulp, paper, and wood chips. Its timber is also utilized in the manufacture of furniture, vinyl products, molding, and sawn wood. The mechanical properties of *A. mangium* wood meet the Indonesian National Standard (SNI) requirements for furniture production (Purwanto, 2012).

Mimosa pigra, native to tropical America, thrives in a variety of habitats, including grasslands, shrublands, natural forests, plantation forests, agricultural fields, coastal zones, riverbanks, wetlands, watersheds, and urban areas, particularly those that are disturbed (Tjitrosoedirdjo, 2024). Its rapid growth rate, strong regenerative capacity, high seed production, and tolerance to drought and flooding make this species highly invasive. To date, no known economic or ecological benefits of *M. pigra* have been identified, and control efforts remain limited to mechanical removal through logging and uprooting.

Calliandra calothyrsus typically colonizes disturbed lands, such as roadsides and shifting cultivation areas, and has the potential to invade forest ecosystems. Despite its invasiveness, this species provides multiple benefits, including firewood, livestock fodder, nectar for honey production, erosion control, and shade (Ty et al., 2001). It has been widely promoted as a fodder source in African regions and is also planted on reclaimed lands to enhance soil nitrogen levels (Setyawati et al., 2015).

Imperata cylindrica was observed in Units 1 and 2 of the Ulubelu PLTP area, with 44 clumps recorded. Although categorized as an IAS, *I. cylindrica* has traditional medicinal uses, including treatments for allergies, ulcers, bleeding, anemia, stomach disorders, and kidney stones (Al Manar, 2018). Its rhizomes contain allelopathic compounds that inhibit the growth of surrounding vegetation, making it a potential source of natural bioherbicides. Bioherbicidal extracts from the rhizomes at a 2% concentration have been shown to effectively suppress weed growth (Sinuraya, 2022).

Melastoma malabathricum, locally known as *herendong* or *senduduk*, is frequently found in open areas, roadsides, degraded forests, and hill slopes (Setyawati et al., 2015). In Units 1 and 2 of the Ulubelu PLTP area, 20 individuals of this species were identified. Although it is classified as an invasive alien plant, *M. malabathricum* has potential applications. Its fruits can be used as natural indicators in acid-base titrations, and ethanol extracts of the fruit have been utilized as a pigment in cosmetic products such as eyeshadow creams (Diana et al., 2022).

Restoration planning

The Ulubelu PLTP is characterized by sloping topography, which contributes to a high potential for soil erosion. Accordingly, implementing vegetation-based soil conservation strategies is critical for maintaining soil stability and preventing erosion. The selection of plant species should be aligned with the site's environmental conditions, including temperature, air humidity, solar radiation intensity, soil pH, and soil moisture levels. The edaphic and climatic characteristics of the Ulubelu PLTP area are presented in **Table 5.**

Table 5. The edaphic and climatic conditions of the Ulubelu PLTP

Line	Temperature (◦C)	Relative Humidity (%)	Solar intensity (lux)	Soil pH	Soil moisture (%)
1	26 - 30	65 - 80	700 - 800	8	< 10
2	30 - 34	52 - 65	800 - 1300	7	< 10
3	26 - 28	79 - 82	200 - 300	7.6	40
4	26 - 30	71 - 81	400 - 500	7.9	20
5	25 - 29	59 - 81	700 - 800	7.5	15

According to the pH value, soils in Ulubelu PLTP can be classified as neutral (6.5-7.5) to alkaline (>7.5) and some nutrients are more available and soluble in acids soil than alkaline soils (FAO, 2021; Bickelhaupt, 2020). Generally, soil pH between 6.0-7.5 are acceptable for most plant because most nutrients are available in this range, but the phosphorus and most micronutrients may become less available. Therefore, it is necessary to slightly lower the pH of the soil so that all nutrients in the soil are more available to plants. One treatment that can be used to slightly lower soil pH is the addition of ammonium sulfate fertilizer, which has a faster effect than sulfur and also provides nitrogen as one of the important macronutrients for plants (Cregg, 2009).

The criteria for selecting suitable tree species include full-sunlight tolerance (light-demanding/intolerant of shade), rapid growth rate, competitiveness against weeds, drought resistance, and the availability of seeds or seedlings. Tree species such as *Cassia* spp., *Gmelina arborea*, *Neolamarckia cadamba*, *Eucalyptus* spp., *Delonix regia*, *Tamarindus indica*, and *Alstonia scholaris* are recommended for planting in Lines 1 and 2, as these species have not yet been identified in the Ulubelu PLTP Units 1 and 2 area. Post-planting evaluation is necessary to assess the planting success rate and to plan for replanting (or gap-filling). Replanting should be conducted if the seedling mortality rate is equal to or exceeds 20%.

The planting of deep-rooted woody species can serve as an effective strategy for soil and water conservation. At the Ulubelu Geothermal Power Plant (PLTP), the recommended restoration species are categorized into three groups corresponding to planting areas B1, B2, and B3. Planting in area B1 should prioritize full-sun, light-demanding species capable of withstanding high solar radiation, reflecting the site conditions reported in Table 5 (elevated irradiance and high canopy openness). In contrast, areas B2 and B3 are better suited to shade-tolerant and moderately shade-tolerant species. Area B2 is recommended for protected plant establishment because it experiences minimal human traffic, reducing disturbance pressure. Spatial recommendations for biodiversity enhancement and soil–water conservation across these blocks shown in Figure 7.

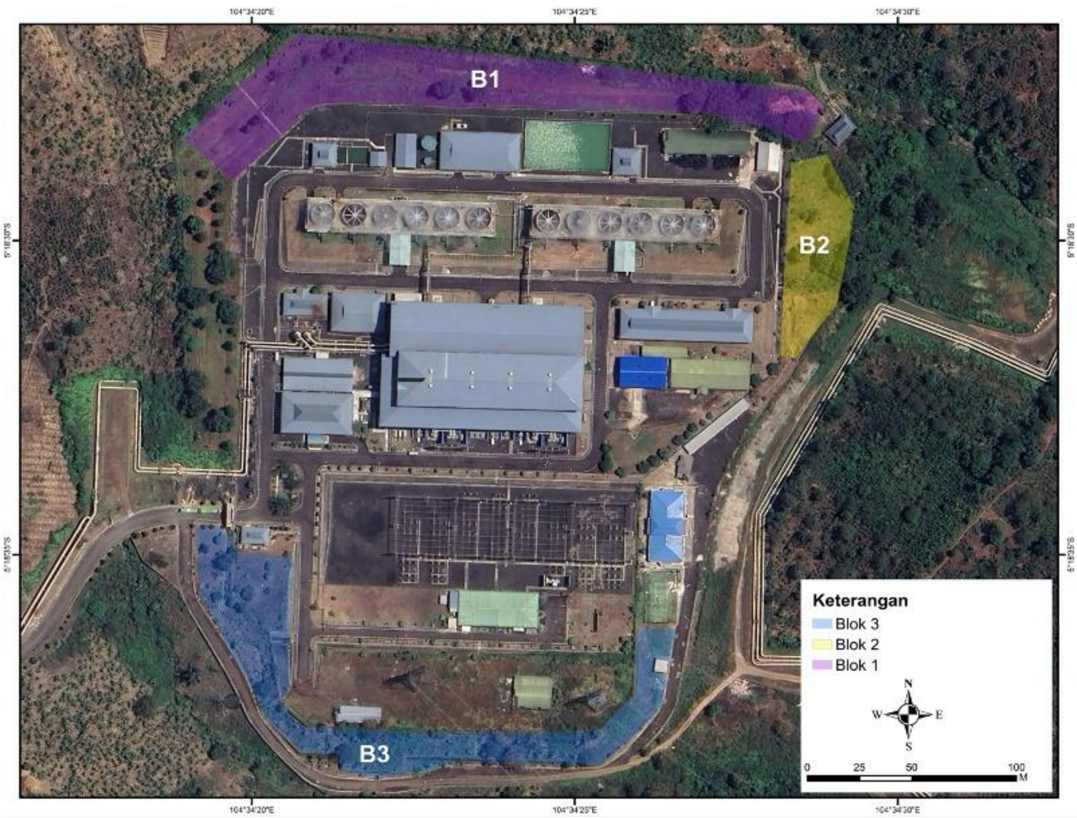


Figure 7. Map of recommended planting locations

The Ulubelu PLTP is situiated at an elevation 780 – 800 m above sea level, with an average monthly rainfall ranging from 300 to 500 mm/month. Based on these data, along with field-measured edaphic and climatic parameters, several plant species are recommended for cultivation to enhance local biodiversity. **Table 6** presents a list of selected species suitable for planting under the prevailing site conditions.

Table 6. Species recommendations for restoration at Ulubelu PLTP

Location	Species	IUCN Status	Utilization
B1	*Garcinia mangostana*	DD	Edible fruit
	Ficus vasculosa	LC	Wildlife food
	Antidesma velutinosum	LC	Wildlife food/medicinal plant (fruit)
	Caesalpinia pulcherrima	LC	Aesthetics (the flowers)
	Baccaurea glabrifolia	VU	Aesthetics (the flowers)
B2	*Dipterocarpus hasseltii*	EN	Conservation
	Shorea javanica	EN	Conservation
	Litsea garciae	LC	Edible fruit
	Cryptocarya sumatrana	EN	Conservation
	Cinnamomum burmanni	LC	Medical plant (leave), spice, food flavour, food preservative
B3	*Stelechocarpus cauliflorus*	LC	Wildlife food/medicinal plant (fruit)
	Litsea garciae	LC	Edible fruit/wildlife food/medicinal plant (fruit)
	Diospyros malabarica	VU	Conservation
	Spathodea campanulata	LC	Aesthetics (the flowers)
	Alseodaphne foetida	VU	Conservation

Annotation: DD (Data deficient); VU (Vulnerable); LC (Least Concern); EN (Endangered)

The determination of planting points and spacing for the recommended species must consider the presence electricity transmission network, in accordance Minister of Energy and Mineral Resources Regulation (Permen ESDM) No. 13 of 2021 concerning the free space and minimum clearance of the electric power transmission network and compensation for land, buildings, and/or plants that are under the free space, then the provisions of the planting distance follow the rules in Figure 8.

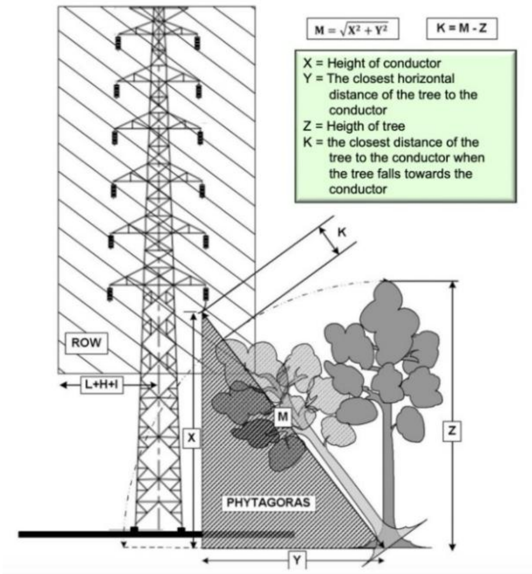


Figure 8. Provisions for distance between plants and electricity transmission

Figure 8 illustrates the recommended height and planting distance of vegetation relative to the electric power transmission network. Very High Voltage Power Lines, referred to in Indonesia as '*Saluran Udara Tegangan Ekstra Tinggi*' (SUTET), require a designated clearance zone to ensure operational safety and system reliability. Consequently, any planting activity near SUTET must account for the potential maximum height of the vegetation. For plant species that are capable of growing tall, a greater horizontal distance from the transmission line is required.

Typically, the height of transmission conductors ranges between 15 and 20 meters. The safe planting distance can be calculated using the Pythagorean theorem, where the maximum allowable plant height must be lower than the variable **M** in the equation, representing the vertical clearance limit. For this reason, the area directly beneath and adjacent to SUTET is commonly maintained as an uncultivated buffer zone. When planting woody species near SUTET, it is essential to estimate the species maximum growth height to determine the appropriate distance from the transmission line, as illustrated in Figure 8.

By regulatory guidelines, plant species suitable for enrichment near transmission corridors include fruit-bearing trees propagated vegetatively, as these typically have smaller stem diameters and limited height growth. Ground cover species may also be established in open areas. Preferred cover crops are fast-growing, drought-resistant legumes capable of enhancing soil properties—physically, chemically, and biologically. Examples of such legume species include *Pueraria javanica*, *Mucuna bracteata*, and *Centrosema pubescens*.

In addition, tree species with the ability to absorb sulfur-containing gases are strongly recommended for planting in areas adjacent to the Ulubelu PLTP, considering the potential emission of hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) from geothermal activities (Munir et al., 2010). Several plant species known for their capacity to absorb SO_2 include: *Polyalthia longifolia*, *Tamarindus indica*, and *Mimusops elengi* (Agathis, 2016).

CONCLUSIONS AND RECOMMENDATIONS

Based on field observations, it was found that upper vegetation strata were not uniformly represented across all growth layers in the study area. This condition is attributed to the regulated planting system of woody species within the Ulubelu Geothermal Power Plant (PLTP) area, where planting distance and tree age are carefully monitored to prevent interference with transmission lines and operational zones. Nevertheless, the analysis revealed that the species diversity in the Ulubelu PLTP area falls into the moderate category, indicating the facility's commitment to environmental sustainability. In areas with high canopy openness and steep slopes, such as Block B1, species enrichment is recommended through the introduction of small-stature multipurpose tree species (MPTS), preferably derived from vegetative propagation to control growth characteristics. In contrast, flatter areas with denser canopy cover are suitable for planting protected or conservation-priority species, thereby reinforcing PLTP Ulubelu's commitment to biodiversity preservation and ecosystem conservation. The Ulubelu PLTP can plant the species Dipterocarpus hasseltii, Cryptocarya sumatrana, and Shorea javanica, which have endangered status and are species found growing in Lampung. The addition of endangered species and fruit-bearing plant species is expected to increase species enrichment and increase the diversity of animals that utilize these plants.

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REFERENCES

Agathis, P. (2016). Inventarisasi jenis-jenis tanaman penyusun Ruang Terbuka Hijau (RTH) dalam menyerap polutan Sulfur dioksida (SO_2) di Kota Yogyakarta. Universitas Gadjah Mada.

Aneke, M., Agnew, B., & Underwood, C. (2011). Renewable energy sources and energy storage systems. *Journal of Applied Energy, 88*(12), 1-12.

Aminah, R., Setiadi, D., & Wahyudi, A. (2014). *Jarak tanam akasia dalam sistem agroforestri di lahan kritis*. Jurnal Kehutanan Tropis, **22**(3), 45-52.

Anjarsari, R., Nugroho, A., & Siregar, I. Z. (2022). *Pengaruh sistem penanaman campuran pada pertumbuhan pinus*. Jurnal Agroforestri Indonesia, **14**(1), 78-89.

Bhat, P. R., & Verma, S. (2002). *Multipurpose Tree Species: An Overview of Their Role in Agroforestry Systems*. New Delhi: Agroforestry Research Institute.

Bickelhaupt. (2020). *Soil pH: what it means*. New York: Department of Forest and Natural Resources Management. SUNY College of Environmental Science and Forestry.

Bošnjaković M, Stojkov M, & Jurjević M. (2019). Environmental impact of geothermal power plants. *Technical Gazette* **26**(5), 1515-1522.

Carlos, D., Pereira, G. A., & Lopez, J. (2022). The role of geothermal energy in the transition to sustainable energy systems. *Renewable and Sustainable Energy Reviews, 150*, 111471.

CBD-UNEP. (2014). Pathways of Introduction of invasive species, their prioritization and management. *Convention on Biological Diversity*, *June 2014*, 18. https://www.cbd.int/doc/meetings/sbstta/sbstta-18/official/sbstta-18-09-add1-en.pdf.

Chen, Y., Zhang, W., Li, X., & Wang, Y. (2019). Impact of geothermal power plants on biodiversity: A global review. *Environmental Research, 172*, 629-643.

Cregg B. Reducing soil pH in landscapes. Retrieved from www.canr.msu.edu

Dhar, A. (2020). Ecological impact of geothermal energy projects on biodiversity and forest ecosystems. *Sustainable Energy Technologies and Assessments, 40*, 100743.

Dhar, A., Smith, P., & Green, M. (2018a). Land degradation and biodiversity loss associated with geothermal energy extraction. *Journal of Environmental Management, 223*, 589-598.

FAO. (2021). *Standard Operating Procedure For Soil pH Determination*. Roma.

Gunawan, A., Suryadi, B., & Wijaya, K. (2021). Geothermal potential and utilization in Indonesia: Challenges and opportunities. *Energy Reports, 7*, 1125-1135.

Harefa, A. R., & Harmok, F. (2021). Seismic activity and geothermal potential in the Indonesian Ring of Fire. *Geoscience Frontiers, 12*(4), 901-915.

Hardja, D, & Vincent, G. (2008). *SExI - FS: User Guide and Software version 2.1.0.* world Agroforestry Centre and Institut de Recherche Pour Le Developpement (IRD).

Ikhsan, Z., Ode, I., Fitrahtunnisa, F., Samson, E., Firmansyah, F., Mariane, I., Ashar, J. R., & Pangestuti, R. (2024). *Keanekaragaman Hayati Tumbuhan*. CV Tohar Media.

International Energy Agency (IEA). (2023). The role of geothermal energy in decarbonizing the power sector. Retrieved from www.iea.org

Jainudin, N. (2023). Deforestasi dan dampaknya terhadap keanekaragaman hayati serta perubahan ekosistem. *HUMANITIS: Jurnal Humaniora, Sosial dan Bisnis, 1*(2), 131-140.

Kalang, J. (2014). *Sistem tanam lamtoro untuk rehabilitasi lahan terdegradasi*. Jurnal Agroekologi, **10**(2), 55-63.

Kimura, F., Sato, M., & Kato-Noguchi, H. (2015). Allelopathy of pine litter: Delivery of allelopathic substances into forest floor. *J. Plant Biol.* **58,** 61-67. https://doi.org/10.1007/s12374-014-0322-8.

Kusmana, C., Wahyudi, A., & Setiadi, D. (2022). *Metode survei vegetasi hutan tropis untuk konservasi biodiversitas*. Jurnal Ekologi Tropika, **18**(2), 112-124.

Kristmannsdottir, H., & Armannsson, H. (2003). Environmental aspects of geothermal energy utilization. *Geothermics, 32*(4-6), 451-461.

Magurran, A. E. (2004). *Measuring Biological Diversity*. Blackwell Publishing.

Manohara, T.N., Balakrishna, S.M., & Suresh, H.S. (2025). Genomic insights of *Dalbergia latifolia* (Indian rosewood): applications in conservation and beyond. *Trees* **39**(39). https://doi.org/10.1007/s00468-025-02617-x.

Margalef, R. (1958). Information theory in ecology. *General Systems, 3*, 36-71.

Munir, M., Fitriani, A., & Wulandari, S. (2010). *Pengaruh emisi PLTP terhadap lingkungan dan strategi mitigasi*. Jurnal Energi Terbarukan, **8**(1), 12-23.

Nurwahyudin, H., & Harmoko, R. (2020). Mapping geothermal energy potential in Indonesia: A spatial analysis approach. *Indonesian Journal of Energy, 6*(1), 55-67.

Nurgiantoro, R., Rahmawati, S., & Setiawan, H. (2022). *Jarak tanam trembesi dan pengaruhnya terhadap konservasi tanah*. Jurnal Konservasi Lingkungan, **5**(3), 98-105.

Peterson, P. M. (2013). *Poaceae: Taxonomy and Distribution of Grass Species in Tropical Regions*. Journal of Botany, **2013**, 1-10.

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology, 13*(1), 131-144.

Ritonga, T., Siahaan, H., & Tampubolon, A. (2020). Identification of potential geothermal power plants in Indonesia. *Indonesian Journal of Renewable Energy, 8*(3), 97-110.

Setiadi, D. (2005). *Dinamika keanekaragaman hayati dalam ekosistem hutan tropis yang mengalami gangguan manusia*. Jurnal Biologi Indonesia, **3**(2), 45-57.

Setyawati, T., Narulita, S., Bahri, I. P., & Raharjo, G. T. (2015). *A Guide Book to Invasive Alien Plant Species in Indonesia*. Research, Development and Innovation Agency Ministry of Environment and Forestry Republic of Indonesia.

Shannon, C. E., & Weaver, W. (1949). *The Mathematical Theory of Communication.* University of Illinois Press.

Soerianegara, I., & Indrawan, A. (2005). *Ekologi Hutan Tropika Indonesia*. Bogor: IPB Press.

Tan, Z. H., Cao, M., & Yu, G. R. (2017). *Optimum temperature range for photosynthesis in tropical forests: A meta-analysis of field studies*. Global Change Biology, **23**(5), 2063-2073.

Tarumingkeng, R. C. (2024). *Peran biodiversitas dalam ekosistem*. Bogor. Institut Pertanian Bogor.

Víquez, A. (2006). Geothermal development and its impact on ecosystems. *Geothermal Energy Journal, 29*(2), 145-156.

Yousefi, H., Mostafaeipour, A., & Qolipour, M. (2019). Investigating the environmental impact of geothermal power plants and their role in CO_2 emission reduction. *Renewable Energy, 138*, 360-374.

Zhang, L., Chen, W., & Huang, J. (2020). Impact of geothermal energy development on local ecosystems: A systematic review. *Ecological Indicators, 118*, 106775.