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Design of Sustainable Agricultural-Based Biomass Electrification Model in the Islands Area: Prospect of Bamboo Biomass

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***Abstract*— In 2020, it is projected that the number of households in the Kepulauan Mentawai Regency will reach 22,534 units in which 9,471 units have received electricity from the State Electricity Company (PLN). By the end of 2020, as many as 1,244 households will be targeted to get electricity from the bamboo biomass power plant that has been built. Thus until the end of 2020, there were still 11,819 household units that would not yet get electricity. The Kepulauan Mentawai Regency Government targets that by the end of 2035 all households will have electricity, by developing electricity using bamboo biomass raw materials. The number of households in the Kepulauan Mentawai Regency until the end of 2035 is projected to be 28,639 units, of which from 2020 to the end of 2035, there will be 17,924 household units including electricity needs. If each household is targeted to get 450 VA power, then the total electricity power still needed is 8,066 KVA or approximately 70,758,160 kWh/year. The bamboo biomass power plant, which will be operated in the Kepulauan Mentawai Regency, currently requires 1.5 kg of dry bamboo to produce 1 kW power with a power factor (*ghospi*) of 0.8. Thus the need for bamboo for power plants is approximately 132,484.1 tons/year. Therefore, to provide this bamboo supply, approximately 714 ha of bamboo is needed.**

***Keyword* —bamboo; biomass; electrification; power plant; bioenergy.**

I. INTRODUCTION

Republic of Indonesia Law No. 30, 2007, article 1, point 25, and Government Regulation N0. 79, 2014 Chapter 1 article 2 mandates that the National Energy Policy's basic principles are fair, sustainable, and environmentally sound to achieve national energy independence and security with the policy direction to realize energy security to support sustainable development. This law also mandates the achievement of increased access of people who are unable and/or who live in remote areas to energy to realize the welfare and prosperity of the people fairly and equitably by assisting to increase the availability of energy for poor and build energy infrastructure for undeveloped regions so as to reduce disparities between regions.

The Government of the Kepulauan Mentawai Regency, West Sumatra Province, is working to carry out this law's mandate, among others by increasing the electrification rate. In 2015, 3 out of 10 districts in the Kepulauan Mentawai Regency did not yet have electricity, namely Southwest Siberut, Central Siberut and West Siberut. Starting in 2017 all sub-districts have received electricity, especially in sub-district centers. In 2018, there were 9,471 households or around 43.9% of the 21,554 households in the Kepulauan Mentawai Regency getting electricity, this figure is up from only around 23.4% in 2014 [1].

Households are the most electricity customers in the Kepulauan Mentawai Regency. Electricity customers of Kepulauan Mentawai Regency in 2014 consisted of 85.69% of households, 2.68% of government offices, 6.85% of businesses and 3.73% of social institutions [2]. This distribution pattern is almost the same until the end of 2019 where household customers are 91.0%, government offices are 1.8%, businesses are 3.8%, and social institutions are 3.2% [3].

The Kepulauan Mentawai Regency is one of the nineteen regencies in West Sumatra Province. Its capital city, Tuapeijat, is located in North Sipora District, which is approximately 174 km from the Provincial Center, which must be reached by sea. The main obstacle in increasing electrification rates in the Kepulauan Mentawai Regency is its relatively large area of 6,011.35 km^2 (14.2% of the total area of West Sumatra Province), consisting of 4 large islands separated by straits, having ten districts, 43 villages, and 266 hamlets spread out inland. The distance between villages

and the distance between hamlets in one village are far apart, while road infrastructure is minimal. Statistical data shows that this area's population density is between 1-8 households per km^2 with an average density of 3 household units per km^2. The average population density of the Kepulauan Mentawai Regency is much smaller than the average population density of the Province of West Sumatra, which is 30 household units per km^2. This condition makes it difficult to increase the power plant's power capacity, but there are also difficulties in distributing electricity, especially for rural households. The position of the Kepulauan Mentawai Regency in West Sumatra Province as shown in Figure 1.

Fig. 1 Map of the West Sumatra Province

The main electricity provider in the Kepulauan Mentawai Regency to date is the State Electricity Company (PLN) by relying on Diesel Power Plants (PLTD). Infrastructure limitations as well as the wide and spreading geographical conditions of the region, require PLN to provide power plants in many locations. This condition makes it difficult for PLN to develop and increase the power plant's power capacity, and it is difficult in terms of fuel distribution to the power plant site, causing high operational costs.

Realizing this condition, the Kepulauan Mentawai Regency Government took the initiative to develop biomass-based electricity, especially utilizing bamboo stems as a source of electricity for electricity generation. This is stated in the Kepulauan Mentawai District Regulation Number 3, 2015, concerning the Spatial Planning and Territories of the Kepulauan Mentawai Regency in 2015 - 2035. Regarding the Energy Infrastructure Network System, it was explained that biomass energy made from bamboo could be developed in each village. The use of bamboo for power sources can be done with a pyrolysis system or gasification in the incinerator. In this system, the solid material is heated at 500 ^{0}C with a little oxygen. This method will produce low dioxin emissions, high electricity generation efficiency, and the charcoal produced can be reused for fuel briquettes and soil conditioners [4]. Biomass conversion technology for energy sources can be done in several ways, including bio briquette, gasification, pyrolysis, liquefaction, biochemistry, and carbonization. The best conversion method for woody biomass is gasification [5]. Biomass power plants have advantages such as having low carbon emissions, protecting

the environment, being a new source of sustainable energy, providing good economic and social benefits [6].

This paper discusses bamboo plants' prospect as raw material for power generation to meet the electricity needs of households in the Kepulauan Mentawai Regency. The research objectives are:

- Projecting the number of households in the Kepulauan Mentawai Regency until 2035.
- Projecting the electricity demand for households in Kepulauan Mentawai Regency until 2035 based on the projection of the number of existing households.
- Calculating the amount of bamboo biomass needed for electrical energy generation to meet households' electrification needs in the Kepulauan Mentawai Regency until 2035.
- Calculating the need for land area for bamboo plants to meet the needs of bamboo biomass until 2035.

II. Materials and Method

The analytical approach is carried out in two ways: forecasting the number of households in the Kepulauan Mentawai Regency, which is intended to calculate the estimated household electrical energy demand in the coming years. The second stage calculates bamboo biomass needed to meet household electrification needs in the Kepulauan Mentawai Regency.

A. Forecasting Number of Households

Forecasting techniques used are the Double Moving Average and test the accuracy of forecasting techniques using Theil U 'Statistics [7]. Forecasting formulation :

$$S'_t = \frac{X_t + X_{t-1} + X_{t-2} + \ldots\ldots + X_{t-N+1}}{N}$$

$$S''_t = \frac{S'_t + S'_{t-1} + S'_{t-2} + \ldots\ldots + S'_{t-N+1}}{N}$$

$$a_t = S'_t + (S'_t - S''_t) = 2S'_t - S''_t$$

$$b_t = \frac{2}{N-1}(S'_t - S''_t)$$

$$F_{t+m} = a_t + b_t m$$

S'_t = Single Moving Average
S''_t = Double Moving Average
a_t = Estimated forecast data
b_t = Variable
N = Order leveling
F_t = Forecasting data

Theil's U-Statistic formula is :

$$U = \sqrt{\sum_{i=1}^{n-1}\left(\frac{F_{i+1} - X_{i+1}}{X_i}\right)^2 \Big/ \sum_{i=1}^{n-1}\left(\frac{X_{i+1} - X_i}{X_i}\right)^2} \quad (1)$$

$\left(\frac{F_{i+1} - X_{i+1}}{X_i}\right)^2$ = Numerator

$\left(\frac{X_{i+1} - X_i}{X_i}\right)^2$ = Denominator

If Theil's U < 1, then the Forecasting method used is relatively accurate.

F = Forecasting data
X = Actual data
i = Period of time

B. Calculation of Bamboo Biomass Needs

Calculation of bamboo biomass needs begins by analyzing the characteristics and potential of bamboo species of betung (*Dendocalamus asper*) that grow around the waters following the land's characteristics in the Kepulauan Mentawai Regency.

Bamboo sampling was carried out in each sample plot measuring 20 x 20 meters, in each sample plot two bamboo trunks were taken that were 3 years old to analyze their characteristics and biomass potential. Calculation of biomass requirements is based on the dry weight basis of bamboo, calculated using the formula [8] as follows:

$$DW = \frac{GW}{1 + \left(\frac{MC}{100}\right)} \quad (2)$$

DW = Dry Weight (kg)
GW = Gross Weight (kg)
MC = Moisture Content (%).

III. Result and Discussion

A. The Actual Number and Projection of The Number of Households in The Kepulauan Mentawai Regency

Data on the number of households is obtained from official government data listed in the Kepulauan Mentawai Regency report in figures from the 2006 issue to the 2019 issue.

TABLE I
Actual Data And Results Of Forecasting Of Number Of Households In Kepulauan Mentawai Regency, 2005-2018

Year	Actual Data of Household (unit)	Forecasting Data of Houshold (unit)
2005	14,645	-
2006	15,294	-
2007	16,192	-
2008	16,527	-
2009	18,476	-
2010	18,988	-
2011	18,381	-
2012	18,133	-
2013	20,259	20,723
2014	20,735	20,931
2015	20,343	20,866
2016	20,747	21,350
2017	21,153	22,096
2018	21,554	22,126

Based on the data series, the number of households that have been compiled then iterates the forecasting model. Model accuracy test results show that the accurate forecasting model is Double Moving Average with 5 orders (N=5). Data on the actual number of households and data on the number of households resulting from forecasting are as shown in Table 1. The pattern of data formed is as shown in Figure 2.

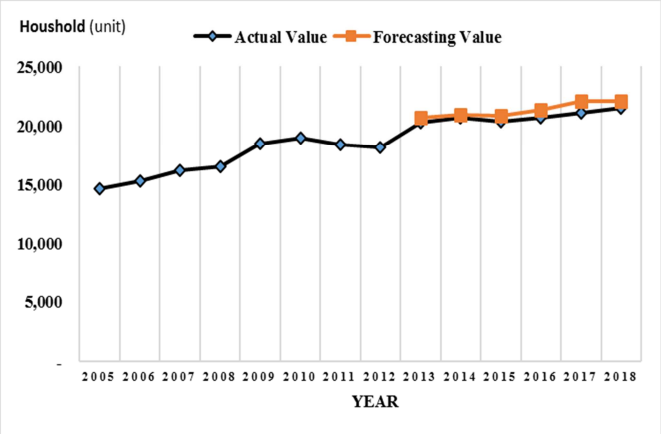

Fig. 2 Data Pattern of Actual Number of Households and Number of Households Results of Forecasting in Kepulauan Mentawai Regency from 2005-2018

The forecasting model accuracy test results show that the forecasting method used is relatively appropriate; this is shown by Theil's U < 1 number. The results of the model accuracy testing are shown in Table 2.

TABLE II
RESULTS OF ACCURACY FORECASTING USING THEIL'S U STATISTIC

Period (i)	Actual Value of Household (unit)	Forecasting Value of Household (unit)	Numerator	Denominator
1	18,133			
2	20,259	20,723	0.00066	0.01375
3	20,735	20,931	0.00009	0.00055
4	20,343	20,866	0.00064	0.00036
5	20,747	21,350	0.00088	0.00040
6	21,153	22,096	0.00207	0.00038
7	21,554	22,126	0.00073	0.00036
Sums			**0.00506**	**0.01579**
Theil's U			**0.57**	

The number of households in the Kepulauan Mentawai Regency in 2018 was recorded at 21,554 units, while households with electricity were around 9,471 units (43.9% of the total households). There are approximately 12,083 household units that do not yet have electricity. If each household that has not yet received electricity will be electrified with 450 VA, then electricity with a power of approximately 5,437 KVA is still needed.

The Kepulauan Mentawai Regency Government has built 3 units of power plants made from bamboo biomass with a total power of 700 KVA. The Mentawai Prosperity Company manages the Biomass Power Plant (PLTBM). It is targeted that by 2020 this electricity can already be distributed to residential houses with a power factor (*cosphi*) of approximately 80% of installed power, and 450 VA will power each household. Thus this plant will be able to supply electricity to as many as 1,244 household units [9]. The bamboo biomass power plant developed on Siberut Island in the Kepulauan Mentawai Regency can generate a cumulative net cash flow of Rp. 144,286,730,000,- in the 30th year [10].

Based on the forecasting model used, namely Double Moving Average with 5 orders, in 2018, the value of ***a*** obtained is 21,720 and the value of ***b*** is 407.Thus in 2020 the number of households in the Kepulauan Mentawai Regency is projected to be 22,534. household unit:

$$F2 = 21,720 + 407\ (2) = 22,534 \text{ household units}$$

If electricity from the existing bamboo biomass plant is already distributed to people's homes, then in 2020 there are still around 11,819 household units that have not yet received electricity, with a total electricity demand of approximately 5,283 KVA.

The Kepulauan Mentawai Regency Government targets that all households will be electrified no later than 2035, according to the motto "Mentawai Bright" in 2035. Based on the forecasting model used, it is estimated that the number of households in the Kepulauan Mentawai Regency in 2035 is as many as 28,639 units.

$$F_{17} = 21,720 + 407\ (17) = 28,639 \text{ household unit}$$

Based on this data, from 2020 to 2035, 17,924 household units need electricity supply (28,639 household units - 9,471 units that have already obtained electricity from PLN - 1,244 units that get biomass electricity). If 450 VA powers each household, the electricity needed is still around 8.066 KVA. Electricity needs for these households which are pushed by the government will be met through electricity made from bamboo biomass.

B. Bamboo Biomass for Fulfilling Household Electrification in the Kepulauan Mentawai Regency

In general, bamboo has a lower calorific value than most biomass raw materials from wood but is higher than most agricultural waste, grass, and straw. Therefore bamboo is good enough to be used as a source of energy from biomass [11]. Proximate test results on bamboo stems showed the value of calories produced was 4,592.54 cal/g [12]. Waste from bamboo plants also produces a relatively large calorific value of around 4,001.57 cal / g [13] and 4,105 cal / g [14]. Bamboo biomass is good for use as raw material for energy sources with a calorific value range of 3,971 - 4,577 KCal/kg [15].

To support the bamboo biomass-based electrification program, the Kepulauan Mentawai Regency Government will develop bamboo plants in the area and the river flow in this area. The survey results show that the types of local bamboo plants that can be used as electrification raw materials in the Kepulauan Mentawai Regency include *Betung* types (*Dendrocalamus asper*). Aside from being a raw material for energy sources, bamboo plants can simultaneously conserve watersheds. Most bamboos have a tight sympodial rhizome root system that can be used for river border conservation [16].

Betung bamboo has a high water content that is 42.61%, but the smallest shrinkage is 13.45%, for that it is suitable to

be used as a source of bioenergy [17]. Betung bamboo has a calorific value of 5,176 cal/g, relatively higher than bamboo *Wulung* which is only 4,873 cal/g, and *apus* bamboo is 5,025 cal/g [18]. The characteristics of bamboo stems growing around the waters are shown in Table 3.

TABLE III
CHARACTERISTICS OF BAMBOO BIOMASS TYPE OF BETUNG (*Dendrocalamus asper*) WHICH GROWS AROUND WATERS

Sample Plot	Height (m)	Weight (kg)	Ratio W/H (kgm^{-1})	Diameter (cm)	Thickness (cm)	Calory ($Kcalkg^{-1}$)	Moisture (%)	Ash (%)	Carbon (%)
Plot 1	24.0	99.9	4.16	22.7	2.27	3,203.2	44.7	1.4	16.0
Plot 2	19.8	85.1	4.31	18.0	2.30	3,636.3	52.6	1.5	16.0
Plot 3	23.5	80.4	3.43	19.2	1.87	3,677.4	43.3	1.2	15.7
Plot 4	18.2	55.0	3.03	17.2	1.88	3,695.7	40.1	1.4	17.4
Plot 5	21.0	78.0	3.71	12.4	3.10	3,911.6	39.7	1.5	16.8
Plot 6	16.3	61.2	3.75	12.6	1.67	3,413.7	37.6	1.3	17.1
Plot 7	22.2	86.9	3.91	11.7	1.75	3,542.7	35.2	1.7	14.7
Plot 8	15.6	58.1	3.73	11.3	1.87	3,512.3	51.3	1.9	17.6
Plot 9	17.2	42.1	2.45	9.9	1.68	3,498.5	49.4	1.4	16.2

The average height of *Betung* bamboo stems obtained from the study site was 19.7 meters, average fresh weight of 71.9 kg/stem, stem diameter of 15.0 cm, the wall thickness of 2.0 cm, and average stem moisture content of 43.8%. The results obtained show slightly different from some other researchers. Betung bamboo that grows in the Subang West Java Province has an average stem height of 15.8 meters, a stem diameter of 11.5 cm, a fresh stem weight of 39.6 kg, and stem wall thickness of 3.9 cm [19]. Other research shows that bamboo species of *Bambusa vulgaris* that grow in the forests of the Lawachara-Bangladesh reserve have an average stem height of 21.92 m with an average stem diameter of 20.57 cm [20]. Betung bamboo that grows in the village of Tanjung Terdana Bengkulu has a plant height between 6.4 - 10 meters, length of sections 29 - 42 cm, stem diameter 6-9 cm, and thickness of the stem wall 1.5 - 2.0 cm [21]. The research results on *Betung* bamboo in Konawe District showed the results of the stem wall thickness of 1.0 - 2.5 cm and stem moisture content of 42.61% [17].

The calorific value of the stem is influenced by the moisture content it contains. Stem moisture content depends on water intake, tree age (growth phase), substrate and external factors. Thus, stems for energy sources need to be first drained and proper storage before use [22].

The average area of bamboo clumps in the study area is 9.88 m2, and the average number of bamboo clumps in 1 ha is 210 clumps, and the average number of bamboo stands in one clump is 22 stems. Thus the average number of bamboo stands in 1 ha in the study area is approximately 4,620 stems. The average weight of fresh bamboo stems is 71.9 kg/stem. Thus the total potential of fresh bamboo biomass is about 332.2 tons/ha. This study's results are relatively higher than the findings [20], where for bamboo species of *bambusa vulgaris*, the number of bamboo stems per ha is 2,933.33 stems with a total biomass weight of 97.8 tons/ha. The study results of the potential of biomass from *bamboo-blanke* species were only 26.3 tons/ha [23].

Observation results at the study site showed that the average density of bamboo plants in a clump was 2.23 sticks per m2, thus the potential number of bamboo plants was 22,667 sticks per ha. When the study was found, there were only 4,620 bamboo stems per ha; this was due to the very large distance between clumps. The results of other studies indicate that the number of *Betung* bamboo stems is 30.2 stems/clumps, the circumference of the clumps is 8.8 meters, and the plant density is 3.2 stems/meters2 [19]. Research conducted in Thailand shows that intensively managed bamboo plants produce higher biomass yields than bamboo plants that are not well managed [24]. The Kepulauan Mentawai Regency Government plans to manage bamboo plants to meet the raw material for bamboo biomass electricity. If the efficiency of the amount of bamboo stands can be achieved only by 50% of the existing potential, then the actual number of bamboo stands that can be obtained is as much as 11,134 stems per ha or at least 2.4 times the current production. The average weight of *Betung* bamboo plants is 71.9 kg/stem. Thus the potential for fresh biomass of *Betung* bamboo plants is 800.5 tons/ha.

The moisture content of bamboo stems will decrease with increasing the stems' age, so the old bamboo stems are relatively good to use as an energy source [24]. Comparison of the number of bamboo stems of *Betung* in the age group on a relatively balanced stretch between stems aged 1 year, 2 years, and three years [19]. Bamboo in Indonesia has very promising potential to be put to good use. Bamboo is a quickly developed plant and has a relatively fast life cycle, with a harvest age of 3-4 years [25]. Bamboo has high biomass productivity, can be harvested at the age of 3 years, the trunk is straight, has high strength, is easily processed, and is relatively inexpensive. Betung bamboo has good characteristics and morphology and its chemical component content can be converted into bioenergy [26].

Based on the data potential of fresh biomass of 800.5 tons/ha and the harvest age is 3 years, the harvest potential of *Betung* bamboo is 266.83 tons/ha/year. The need for bamboo biomass for power generation needs is calculated based on the bamboo plant's dry weight. Based on fresh bamboo biomass's potential, dried Betung bamboo's weight potential per hectare per year is estimated at 185.56 tons.

$$DW = \frac{266.83\ kg}{1 + \left(\frac{43.8}{100}\right)}$$

DW = 185.56 ton/ha/year

Bamboo gasification provides excellent prospects for increasing added value and utilizing bamboo as a raw material for generating electricity. Biomass gasification is the main way of biomass energy utilization in Beijing [27]. Not only bamboo stems, but also waste from bamboo processing can also be used for gasification. This encourages a commitment to producing clean electricity from renewable natural resources that can substitute for the use of fossil fuels and reduce operating costs [11].

Every 3-4 kg of fresh biomass from bamboo plants can produce electricity as much as 1 kWh. The potential energy produced is the same as that produced by using as much as 1 liter of diesel [28]. The use of bamboo as an electrification raw material for power capacities <1 MW to 2 MW is very suitable using the "Biomass Power Plant-Gasification System-Pyrolysis". The use of this system will require approximately 1.22 kg of biomass with 15% moisture content to produce electricity of 1 kWe [29].

Some research data relating to the use of biomass as a raw material for electricity generation has been widely published. in Thailand, power plants made from corn cob biomass with a mixture of several types of agricultural waste with a capacity of 150 KW require 224 kg of biomass/hour (approximately 1.49 kg of biomass/KW). Other biomass-based power plants in Thailand with a capacity of 500 KW using raw materials of 60% wood chips and 40% corncobs require raw materials of 5,389 tons/year or approximately 1.23 kg of biomass to produce 1 KW of electricity [30]. Mentawai Prosperity Regional Company Management said that the power plant made from bamboo biomass, which is already owned by the Kepulauan Mentawai Regency, currently requires 1.5 kg of dried bamboo to produce electricity of 1 KWe.

The electricity needed to meet household electrification in the Kepulauan Mentawai Regency in 2020 is 5,283 KVA. If electricity is fully operated for 24 hours per day and 365 days per year, and the power factor (chospi) is 0.8 then in 2020 the electricity needed is 46,279,080 KWh, the need for dried bamboo is 86,773.3 tons/year, and the area of bamboo needed is 467.6 ha.

EPR = 5,283 KVA x 24 hours x 365 days
= 46,279,080 KWh
DBN = 46,279,080 x 1.5 kg x (1/0.8)
= 86,773.3 tons/year.

EPR = Electrical Power Requirements
DBN = Dry Bamboo Needed

The area of bamboo plants needed to meet household electricity needs in 2020 are:

$$Bamboo\ Area\ Plant\ Needed = \frac{86{,}773.3\ ton}{185.56\ ton/ha} = 467.6\ ha$$

The projected need for electrical power to meet household electrification in the Kepulauan Mentawai Regency in 2035 is 8,066 KVA. Using the same assumptions as of 2020, the electricity needed is 70,658,160 KWh, dry bamboo needed is 132,484.1 tons/year, and the required area of bamboo plants is 714 ha.

EPR = 8.066 KVA x 24 hours x 365 days
= 70.658.160 KWh
DBN = 70.658.160 x 1,5 kg x (1/0,8)
= 132.484,1 ton/year

The area of bamboo plants needed to meet household electricity needs in 2035 are:

$$Bamboo\ Area\ Plant\ Needed = \frac{132{,}484.1\ ton}{185{,}56\ ton/ha} = 714\ ha$$

In the Kepulauan Mentawai Regency Spatial and Regional Planning for 2015 - 2035, it is stated that it will develop 300 hectares of bamboo for each island. Mentawai Islands Regency consists of 4 large islands, thus the government has targeted there will be the development of bamboo plants on an area of 1,200 ha by 2035.

IV. CONCLUSIONS

The projected number of households in the Kepulauan Mentawai Regency until the end of 2020 and 2035 are 22,534 units and 28,639 units, respectively. In 2020 there were still 11,819 households that had not yet received electricity, and by the end of 2035, there were an estimated 17,924 household units that would need electricity. If each household needs 450 VA of electricity, then electricity is still needed for households in 2020, and by the end of 2035, each is 5,283 KVA and 8,066 KVA. In order to meet the electricity needs of the aforementioned household, the Kepulauan Mentawai Regency Government is using electricity made from bamboo biomass. Bamboo biomass needed to meet the electricity power in 2020 and at the end of 2035 is 65,777.3 tons/year and 132,484.1 tons/year, respectively. To meet the bamboo biomass needs, there must be bamboo plantation land for 2020 and at the end of 2035, covering 467.6 ha and 714 ha, respectively.

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