Green prosperity: a natural-based solution for rural electrification in Indonesia

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Abstract. Primary energy demand in Indonesia is growing rapidly due to urbanization, economic growth and population increase. The contribution of New and Renewable Energy to the national energy mix is mandated to reach 23 % by 2025. Indonesia’s Nationally Determined Contributions (NDC) stresses five sectors in which greenhouse gas (GHG) emissions are to be reduced with forestry and energy being the highest priority. While Indonesia is committed to address climate change through the forestry sector, there are clearly contextual challenges that need to be addressed to create the enabling conditions for REDD+. Biomass production for local energy supply in remote and rural areas could become the agent of change for this difficult problem. This paper proposes a methodology for rural electrification using a community and biomass-based power generation system exemplified by a real case in the Mentawai islands in Indonesia. By replicating this proven system that results in biomass production, land restoration, affordable electricity, and local economic growth, the contribution of renewable energy in the energy mix and the overall prosperity of Indonesians in rural and remote areas can be improved.

1. Introduction
Promoting renewable energy in Indonesia requires extraordinary effort, because many of the islands across the entire country do not have reliable grids. This condition makes island-grids dependent on mostly diesel-powered generators that can provide power on demand in between islands. Based on the National Electrification Ratio, Indonesia has successfully connected 97.5 % of households to the electricity grid [1]. However, the effort to achieve universal electricity access is difficult, especially for the people living in small islands, far inside the jungle, or highly separated from major human settlements [2].

One of the main limitations of diesel-powered generators in remote areas is the costly operational expenses. Delayed fuel shipments due to bad infrastructure and unpredictable weather can cause these generators to run out of fuel [3]. Increasing the renewable energy portion turns out to be challenging as well. Applying solar and wind energy is difficult since solar and wind energy have intermittent behaviour (see [4], [5] and others). Additional high-cost apparatus, such as battery, liquid energy storage, or other form of storage are necessary to close the gap. Thus, the investment cost of renewable energy could considerably be higher than the similar investment in other countries or even more expensive than the diesel-based power generation. Indonesia’s state utility company (PLN) has considered using a hybrid scheme with diesel power plants [6]. The renewable energy-based power
plants act as the main power source and the diesel plants maintain the power supply stability and overcome the intermittent behaviour of the renewable energy. However, this scheme is difficult to implement as diesel power plants still require reliable fuel supply from other islands.

On the other hand, some renewable energy resources promise characteristics of continuous and stable electricity supply, owing to its perpetual sources of energy [7]. Hydro, geothermal, and biomass are among those sources of renewable energy in Indonesia [8]. Continuous load renewable energy is crucial in the development of archipelagic regions due to its capability to supply base load independently without additional hybrid connection using fossil energy. However, some renewable energy sources have obstacles related to development in small islands.

Hydropower (see [9], [10] and others) derives from the energy of water moving from higher to lower elevations. This certain requirement is inconvenient in many islands as the river is short and the water level low. Furthermore, some rivers are located remotely from the centre of demand, which causes significant energy loss. This situation is identical with geothermal (see [11], [12], [13] and others), whereby not every island has geothermal resources beneath the earth-crust and most of geothermal sources in Indonesia are located in the mountains. A long transmission is crucial and thus makes it inefficient due to energy loss. Furthermore, the capacity of geothermal power plants is relatively high due to its high investment cost. Thus, developing geothermal for small-scale mini-grid, which is needed for small islands, is inefficiently unsuitable. Local biomass, on the other hand, can be utilized to create small-scale power plants that can be placed near to the center of demand in small islands in Indonesia. Thus, renewable energy based on local biomass has the potential as a solution for small-scale power plants in small islands in Indonesia.

Biomass resources consist of many different types (see [14], [15] and others), including residual forestry waste, woody and non-woody forestry products, animal residue, sewage, and municipal solid waste. Indonesia has a huge potential as a biomass producer, including the small island areas [7]. Biomass can be produced locally and in the vicinity of the power plant; hence the plant is manageable in almost every area near the centre of electricity demand.

This paper proposes a system to use small-scale biomass gasification1 as a solution for small-scale power plants in small islands in Indonesia. Gasification process on a small scale is technically matured and behaves more like diesel-powered generators rather than direct combustion of biomass combined with steam turbines. As the high-end gasification technology in waste and ash management, it has lower emissions of NOx and SOx, more efficient heat, and fewer requirements of consumables. It is widely reported that gasification is appropriate for small-scale capacities from 10 kWe up to 1 MWe. Therefore, small scale biomass gasification is preferable for the electrification of small islands because of its capability of utilizing local resources and its ability of providing reasonable cost of electricity as no energy storage is required for the system.

In the proposed system, the biomass is directly purchased from the communities, thus supporting local economic growth. Moreover, the effort of land restoration is supported in this system as the biomass planting area is selected to maintain land stability, reinforce degraded land, and sequestrate CO2 significantly. This paper also proposes REDD+ payment to fund land restoration using bamboo or other perennial plants, which can be used as feedstock for small scale biomass gasification power plants.

This paper will highlight the proof of concept of the proposed system in the Mentawai Islands, West Sumatra, Indonesia. The electrification ratio in the Mentawai Islands at 29.8 % is significantly lower than the national average, 97 %. The power plants consist of 3 separated plants in 3 isolated villages: Madobag village (300 kW), Matotom Village (150 kW), and Saliguma Village (250 kW). All of the power plants are supported by local forest biomass, particularly bamboo. Owing to its capability to reinforce degraded land, intercropping behavior, and high calorific value, bamboo is selected and planted massively in the Mentawai social forest managed by the villagers. This proven

1 gasification converts solid biomass into combustible gases
strategy in Mentawai will serve as a model for replication of small scale biomass gasification power plants in other islands with low electrification ratio.

The contributions of this paper are the following:

- This paper proposes a methodology of rural electrification in Indonesia that is based on renewable energy, covering social-economical-political aspects of electrification.
- This paper proposes a business model whereby rural electrification and employment creation are carried out simultaneously, promoting sustainable development of the rural areas. The business model shows that a community biomass-based power plant can be funded by carbon credit payment.

The rest of the paper is organized as follows: Section 2 elaborates on the problem description and the proposed methodology. Section 3 reviews the socio-economic condition of the Mentawai Islands prior to the biomass gasification project. Section 4 focuses on the implementation of the biomass gasification project in the Mentawai Islands, followed by the conclusion in Section 5.

2. Problem Description and Proposed Methodology

2.1. Problem Description

The problem in this paper is to formulate a solution for rural electrification in Indonesia that satisfies the following conditions:

(C.1) The energy source is renewable and can be obtained locally;
(C.2) The effect of the harvesting process of the energy source to the ecological system is minimal and must involve forestation effort;
(C.3) The generation system must be dispatchable and scalable;
(C.4) The electricity produced must be equitable, reliable and affordable.

The first part in point (C.1) is mandatory to support the Indonesian government plan to reach 23% of renewable energy contribution to the national energy mix by 2025. The second part in point (C.1) is proposed to tackle two things:

- to minimize the raw material cost
- to create local employment which in turn will boost the local economy

The effect of the two things above can be seen clearly in the economic aspect of the proposed solution, i.e. low cost of electricity generation, which makes the electricity more affordable, and the creation of local employment, which results in a more sustainable living. The community can afford to purchase the electricity since they have a source for living, and in turn, the electrification is sustained since there are people who purchase the power generated from it.

Point (C.2) strengthens the first part of point (C.1). Suppose the energy source is renewable, for example solar-based, but the installation of the solar panels requires deforestation, then the harvesting process of the solar energy clearly destroys an ecological system. Deforestation affects albedo and evapotranspiration and it also causes consistent warming. The forestation effort however is aligned with the Indonesian government's NDC and in addition, it will enable REDD+ conditions.

The first part of point (C.3), dispatchability, is a mandatory requirement for a power generation. Meanwhile, the second part of point (C.3), scalability of power generation, is needed since the electrification is meant for rural areas where the population is distributed unevenly due to geographical conditions. On the other hand, electrification could push industry growth in rural areas which possibly will create greater energy demands in the future.
Point (C.4) is dominantly affected by the business and political situation surrounding the power generation. Electrification in rural areas greatly depends on the funding and the management of the funding involves central government, local government, and the private sector. Equitable means that the electricity produced must benefit all stakeholders. This way, politically, the electrification will be sustainable. Reliable electricity means that the electricity produced must be robust to any changes in the economic, social and political situation. Lastly, affordable electricity means that the rural community is able to purchase it without sacrificing their primary needs.

Conditions (C.1)-(C.4) ensure the workability and sustainability of the electrification in rural areas. We see that REDD+ condition alone is not sufficient to make the whole development workable and sustainable. There are economic, social and political issues that must also be considered.

2.2. Proposed Methodology
The purpose of the formulation of the methodology is such that the same results in Mentawai Islands could be reproduced in other rural areas. The formulation consists of seven steps:

(M.1) Determine the Rural Area to be Electrified
The rural area that becomes the priority to be electrified is the area with low electrification ratio and it should also be the area where the government puts attention or effort in electrifying. This area is commonly called as 3T (Terdepan, Terpencil, dan Tertinggal) which translates into a border area that is isolated and underdeveloped. When the chosen area is aligned with the government plan, there will obviously be less political issues. Currently, according to [16], there are 48 3T areas in Indonesia that need to be electrified with a required capacity between 5 - 10 MW.

(M.2) Selection of Renewable Energy Source
The renewable energy source must be selected to comply with conditions (C.1) and (C.2). Therefore, the only suitable renewable energy source is biomass that can be obtained by forestation, for example bamboo (see [17], [18], [19] and others).

(M.3) Establishment of Business Model
The business model must be established before any engagement with other stakeholders and the business model must facilitate the following:
- local employment creation
- equitable electricity production
- sustainable electrification

Figure 1 shows the proposed business model where BPDLH (see point (M.6)) interacts with the local community, IPP (Independent Power Producer), and PLN (Perusahaan Listrik Negara or National Electricity Company). The local community plants the biomass and sells it to the IPP. IPP produces the electricity and sells it to PLN and PLN sells the electricity to the local community. Since forestation is involved in the electrification, the system is entitled to the incentive from REDD+ that will be managed by BPDLH. This paper proposes that the carbon credit payment is used to create employment opportunities and also to reduce the electricity price in the long run.

To the best of the authors’ knowledge, the business model in Figure 1 is the first model that connects preservation of the environment with the creation of employment and rural electrification. Even without the carbon credit payment, the interaction between (1), (2) and (3) of Figure 1 guarantees sustainable electrification. However, the additional carbon credit payment will help a faster development of rural areas and it will also give additional warranty of sustainable electrification due to a low electricity price. Ultimately, the carbon credit can be used to cover the capital expenditure to start the development of rural electrification project.
(M.4) Obtain an MoU with the Local PLN
In Indonesia, PLN is the official entity that can sell the electricity to the public in Indonesia. Therefore, PLN must be involved in the electrification plan of the rural area. The local PLN must be convinced to purchase the electricity produced by the IPP so that the business model in Figure 1 can be implemented.

(M.5) Feasibility Study
Feasibility study must be carried out to predict the economic value of electrification. The result from this study can be used as justification of the electrification plan on both social and political level.

(M.6) Securing the Development Fund
One of the reasons that Indonesia still has many areas with low ratio of electrification is the lack of funding. By conforming to conditions (C.1)-(C.4), the rural electrification plan is entitled to the funds managed by BPDLH (Badan Pengelola Dana Lingkungan Hidup or Ecological Funding Management Bureau) [20]. BPDLH is the national agency that manages funds related to forestry, energy and mineral resources, carbon trading, environmental services, industry, transportation, agriculture, marine and fisheries and other fields related to the environment. The source of funding managed by BPDLH can be categorized as follows:
- Carbon/emission trading
- Soft loans, senior loans, and subordinated loans
- Conventional grant
- Subsidy on environment related issues
- Government support in form of VGF (Viability Gap Fund)
- Equity

(M.7) Detail Planning of the Electrification
Last but not least is the detailing of the technical planning of the electrification consulted with all stakeholders. This step can be carried out once the steps (M.1) - (M.6) have been finalized. This step will not be discussed in this paper.

Figure 1. The proposed business model for rural electrification in Indonesia: (1) Represents the local community. (2) Represents the (IPP). (3) Represents National Electricity Company (PLN).
3. Review on Socio-Economics of Mentawai

3.1. Geographical Condition Summary

Kepulauan Mentawai Regency (kepulauan means archipelago) is located in the province of West Sumatra with geographical position between 00 55’00” – 3 0 21’00” South Latitude and 980 35’00” – 1000 32’00” East Longitude. The area is roughly 6,011.35 km² with a coastline of 1,402.66 km. Geographically, the land of Mentawai Regency is separated from the province of West Sumatra by sea waters. The boundary on its Northside is the Siberut Strait, on its Southside and Westside is the Indian Ocean, and on its Eastside is the Mentawai Strait. In summary, Mentawai Regency lies isolated at the border of Indonesia.

Mentawai Regency consists of a group of 99 islands where one of them, Siberut Island, is larger than others. Mentawai Regency has 10 districts and 43 villages [21]. Geographically and administratively, Mentawai Regency consists of 10 sub-districts, 43 definitive country sides and 341 definitive orchards. Topographically, the geographical situation of Mentawai Regency varies among plains, rivers, and hills up to 2 meters from sea level. Mentawai Regency capital is located in the Sipora Utara sub-district called Tuapeijat.

Based on [21], the forest area in Mentawai Regency is 456,301 ha or 76% of the total area of Mentawai itself. Only 3,096 ha or 0.5% is used for residency of the population. On average, the distance of the capital sub-districts in Mentawai Regency to Tuapeijat is 94 km. With 99 islands spread throughout the Regency, boats or speedboats are the main transportation of the population to travel from their sub-district to the Regency (Tuapeijat).

3.2. Population in Mentawai

The population of Mentawai Regency in 2018 is 90,373 consisting of 46,998 males and 43,375 females. Meanwhile, 12,990 of the population are categorized as poor [21]. The regency’s Human Development Index (HDI) is 60.28 and it is below the HDI of West Sumatra Province, which is 71.73. The population density of the Mentawai Islands in 2018 is 15 people per km² on average. The highest population density exists in Sikakap sub-district which is nearly 37 people per km². On the other hand, West Siberut sub-district has only 7 people per km².

The total of 15 years and over population in Mentawai Regency is 57,790. Economical activities of the population are shown in Table 1.

| Main Activity          | Male | Female | Total |
|------------------------|------|--------|-------|
| Economically active    | 25,008 | 18,172 | 43,180 |
| Working                | 24,621 | 17,579 | 42,200 |
| Unemployed             | 387    | 593    | 980   |
| Economically inactive  | 5,379  | 9,231  | 14,610 |
| Attending school       | 3,075  | 3,085  | 6,160 |
| Housekeeping           | 751    | 6,031  | 6,782 |
| Others                 | 1,553  | 115    | 1,668 |
| **Total**              | 30,387 | 27,403 | 57,790 |
From Table 1, the unemployment rate, \( \frac{\text{unemployed}}{\text{economically active}} \times 100\% \), is 1.55 % for male and 3.26 % for female. Meanwhile, the economic participation, \( \frac{\text{economically active}}{\text{total population}} \times 100\% \), of male is 82.3 % and for female is 55.31 %.

The education attainment of residents who are economically active [21] is shown in Table 2.

**Table 2.** Population Aged 15 Years and Over who are economically active by education attainment.

| Education                        | Working | Unemployed | Total  |
|----------------------------------|---------|------------|--------|
| No education or did not complete primary school | 14,125  | -          | 14,125 |
| Primary school                   | 12,741  | 119        | 12,860 |
| Junior high school               | 5,773   | 79         | 5,852  |
| Senior high school               | 6,793   | 782        | 7,575  |
| Diploma I/II/III                 | 813     | -          | 813    |
| University                       | 1,955   | -          | 1,955  |
| **Total**                        | 42,200  | 980        | 43,180 |

From Table 2, almost half of the economically active population is either has no education or only finished primary school.

3.3. *Electrification in Mentawai*

Electrification ratio of Mentawai Regency is only 29.8 % [18], which is below the average of West Sumatra’s electrification ratio (86.6 %). Most of the areas in the Mentawai Islands use diesel power plants operated by PLN, which are not capable of operating for 24 h. The PLN division of Mentawai Regency stated that the number of customers until December 2013 is 5,524 customers spread over 10 districts. This is an increase from 2012 and it is projected that the number of customers will increase even more in the upcoming years.

In 2013, the biggest number of PLN's customers was in the North Sipora sub-district with 2,223 customers (40.24 %), most of them living in the Tuapejat village. This is followed by the South Siberut sub-district with 966 customers (17.49 %), having it’s electricity consumption centre in Maileppet Villages. The South Sipora sub-districts have 862 customers (15.60 %) with its’ centre in the Sioban villages.

The number of PLN's customers obtained above is according to the tariff faction, and this covers social, household, business, and government use. The biggest chunk of customers comes from household usage, which counts for 4,849 customers (85.69 %). Meanwhile the segment that counts the least amount of customers comes from governments’ offices, which totals for only 134 customers (2.43 %).

3.4. *Remarks on Socio-Economics of Mentawai*

Based on the discussion above, Mentawai Regency is considered one of the top priority areas to be electrified in Indonesia. It is a 3T area, its electrification ratio is very low, and most of the power plants in Mentawai Regency run on diesel and are incapable of providing electricity for 24 h. Adding more power plants to Mentawai will increase its electrification ratio and there is potential for
replacement of the diesel power plants by the GHG emission reducing, renewable energy-based power plants.

From Table 1, Mentawai people are economically active. Meanwhile, they are familiar with the local biomass (bamboo). By implementing the business model in Figure 1, Mentawai people will be incentivized; they will have more employment opportunities, and they will have more access to electricity. Thus, the proposed business plan will be a positive contribution to the local economy and the wellbeing of the Mentawai people.

The rural areas in the Mentawai Islands are a 5-h express boat ride away from the main cities. Thus, the power plant must be developed right in the centre of the rural area and it must be self-sufficient, i.e. the source must be obtained locally. This is also the reason why diesel power plants are very expensive in the Mentawai Regency, and therefore a distributed power plant that uses local sources of energy provides a better option.

4. Biomass Gasification for Power Generation in Mentawai

The biomass gasification project in the Mentawai Islands is implemented by Clean Power Indonesia (CPI). In this project, the initial funding is obtained from a grant by Millenium Challenge Account (MCA). The total funding of this project is USD 13.4 million (including DFS), where 96 % of it is covered by the MCA grant. CPI took on the role of IPP and the MCA grant is also applied and obtained by CPI. The detailed technical planning (engineering, construction, and procurement) was carried out by the contractor.

The main purpose of this project is to introduce and develop renewable energy power plants in rural areas that cannot be reached by PLN. Prior to the project implementation, CPI approached the local PLN to convince them of this project’s merits and benefits for all stakeholders involved. This is the step (M.4) discussed in section 2. It is to emphasize that the power plant developed by CPI is owned by the Indonesian government and eventually the local community, and that CPI’s role is merely the developer and enabler. The electricity produced from the biomass gasification will be sold to the public and managed by PLN.

In this project, bamboo is chosen as the biomass source. The choice of bamboo as the renewable energy source conforms to conditions (C.1) and (C.2) because it has minimum impact on the existing ecosystem and helps flourish the forestry. The following are the most important reasons behind the selection of bamboo as the biomass source in this project:

- Bamboo is socially acceptable in the Mentawai Islands, i.e. the people have deep familiarity with bamboo for generations
- Bamboo has a small ecological footprint, i.e. bamboo is planted on marginal land
- Bamboo is supported by a legal framework as a community-based plantation, i.e. the Ministry of Ecology and Forestry of Indonesia recognizes bamboo as restoration plantation [22]
- Bamboo is suitable as fuel in biomass power plants [23]

The illustration of the project implementation in the Mentawai Islands is given in Figure 2. The fuel for the power plant is the syngas from the bamboo gasification process. Meanwhile, the gasification process also results in ashes and charcoal that can be used as cooking fuel. In addition, the exhaust gas from the bamboo biomass-based power plant can be used for drying the crop. Therefore, the use of bamboo is optimal to support the economic activities of the rural population.
The locations of the gasification project that started in 2018 are the villages Madobag, Matotonan, and Saliguma on Siberut island. The Madobag and Saliguma villages can only be reached by boat in 3 to 5 hours respectively from the main city in Siberut. On the other hand, Matotonan village can only be reached by walking for 8 hours or by a boat trip for about 6 h. The total power plant capacities for the three villages are 700 kW and it covers 1,181 households and 456 non-residential connections. Figure 3 shows the first light from the bamboo biomass-based power plant in Saliguma village, which is also the first light from the first bamboo biomass power plant in Asia Pacific.

Bamboo as the biomass source is provided by the community (refer to Figure 1). Every household receives 100 bamboo seedlings, where: (i) 1 seedling equals to 100 poles within 5 years and (ii) 1 pole weighs 20 to 30 kg. Thus, roughly, 1 household needs only 2 to 3 poles per month to fulfil their own energy needs. The community role in supplying bamboo is illustrated in Figure 4. Figure 4(a) shows people collecting and transporting bamboo poles from the plantation. Figure 4(b) shows people drying the cut bamboo poles (they need to be dried for 3 days) and preparing them for collection by IPP. Figure 4(c) shows the representative from IPP collecting the dried and cut bamboo poles to be processed further at the power plant. In the implementation, the amount of bamboo that needs to be
supplied by each household is determined by consensus-decision making in the village. This is done to avoid over-supply of bamboo to the IPP.

Data from [24] shows that the employment opportunity created by the gasification project in the Mentawai Islands is roughly IDR 2 billion per year. This number includes the contribution of the community to supply bamboo to the IPP and the employment opportunities at the IPP that are open for applicants from the local communities. Meanwhile, from [25], the jobs created from the biomass gasification project lead to a total of 450 employees. The employment creation is an important aspect of the business model proposed in Figure 1.

Following are the properties of biomass gasification project in the Mentawai Islands:

1. **Land Concession.** The local government gives the right to the local community to use the land to plant bamboo, which ensures the supply of the biomass power plant. In return, this land concession results in forestation.

2. **Accessibility.** The electricity produced in Siberut Island from the biomass power plant is managed by the local PLN. Thus, its accessibility to the local community can be guaranteed.

3. **Affordability.** The local community that supplies the raw energy source to the IPP obtains incentives. The local community will then have (additional) income that can be used to purchase the electricity managed by the local PLN. Therefore, the local community is able to afford the electricity.

4. **Acceptability.** The existence and planting of bamboo is socially acceptable for the people of the Mentawai Islands. The local government also supports the planting of bamboo because it has always been done on marginal or unproductive land. From an outsider’s perspective, the planting of bamboo is widely accepted since it reduces GHG emission.

5. **Sustainability.** The business model in Figure 1 is sustainable due to the sustainable supply of the biomass source (see point (i) above). Meanwhile, the business of the IPP is sustainable due to the sustainable supply of the biomass source and purchase of electricity from the local PLN. Lastly, the local PLN maintains a sustainable customer amount and can benefit from the fund managed by BPDLH to reduce the electricity price.
Figure 4. Documentation by CPI: People in Mentawai: (a) Collecting and transporting bamboo poles. (b) Drying the cut bamboo poles and preparing it for collection by IPP. (c) IPP representatives collect the dried and cut bamboo poles.

5. Conclusions
The gasification project in Mentawai discussed in this paper conforms to the conditions (C.1)-(C.4). In addition, the project in Mentawai have shown that the methodology (M.1)-(M.7) proposed in this paper can successfully realize the electrification of rural area in Indonesia by using renewable energy.

The development fund for the gasification project in Mentawai comes from the MCA grant. Although this grant cannot be reproduced in other areas, the project in Mentawai has shown that similar projects in other areas are entitled to the fund managed by BPDLH, which can be used to start the development.

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