The attainment of 100 percent electrification ratio in the archipelago of Indonesia by people way electricity initiative

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Abstract. The electrification ratio in Indonesia has reached over 90 percent already but it is not easy to attain the rest of people who have not gotten the light because they are living in the scattered and isolated areas over several thousand islands in the archipelago of Indonesia. Conventionally, the electricity service in Indonesia is developed by using a centralized and interconnected of various large scale units of power plants. However, many big project of a large size power plant is currently facing many challenges including land and acquisition, financial closing, complex permit procedures, and right of way for transmission lines. As a result, the cost of such conventional system cannot be offset by the expected efficiency from a better reliability and economies of scale of such conventional system. To address this problem, the School of Technology STT PLN Jakarta, proposes an initiative namely ListrikKerakyatan (LK), which is a simple and small scale self manage electricity development by local people empowerment using renewable energy available around the communities. After passing several pilot projects, This LK initiative has already successfully implemented in Klungkung District, Bali, using the model, called TOSS (TempatOlahSampahSetempat), stands for localized municipal waste treatment. The pilot project shows that a 30 kW gasifeier genset including its associated unit TOSS for 3 ton of waste is cost around USD 40 thousands, the cost of which is still less than rural funding available from national budget. LK needs relatively little operational cost since its fuel is made from municipal waste.

1. Introduction
The archipelago of Indonesia conjunct of around 17,000 islands, where people are living in more than 3000 islands that makes the electricity development of this country is challenging. Therefore, many people in Indonesia who live in the small and scattered islands still have no electricity because the conventional electricity using interconnected large-scale power plants cannot be applied in this archipelago. Although the national electrification ratio (ER) has reached 97.5%, the rest three percent of people who have no light are mostly living scattered in many small islands. Even in the developed areas like in Java and Sumatra, there are some houses that still have no light because they are living in the remote and isolated areas that far from the available electric network. Usually, such remote areas can get electricity from diesel power plant, which operational cost is very high due to the expensive diesel fuel cost and transportation cost. In order to attain the target of 100% electrification ratio, the government still relies on using distribution lines as mentioned in the electricity national business plan (RUPTL) 2018-2027. There are other options like rooftop solar PV or a hybrid of diesel and solar
PV but the intermittency of PV is still hard to compete with the conventional distribution lines system. Actually, there is another alternative that may be more sufficient for rural electrification, using small scale renewable energy, namely ListrikKerakyatan (LK), which cost is cheaper and can be owned and managed by local people [1-3]. ListrikKerakyatan is a property right of Sekolah Tinggi Teknik PLN which name is taken from Bahasa Indonesia, like Japanese name Kaizen or Osaki.

The study in this paper will answer the question, in which conditions, LK as the new approach of rural electrification, is technically comparable and economically better than the conventional distribution lines. The comparison is conducted by simulation and the scope of study is limited from the available data that are stipulated in Indonesia Electricity National Business Plan (RUPTL) 2018-2027 [4]. As written on the national electricity business plan (RUPTL) 2018-2027, the government has declared the target of 100% electrification ratio (ER) by the end of 2019. The target is planned to be fulfilled by electrification of all rural areas, since many people that get no electricity are living in rural areas including those are located on the most outer islands of this country.

Until recently, the small system under 10 MW for remote and isolated areas is electrified using diesel plant. The effort to build small size coal power plant to reduce diesel fuel consumption was failed because it was not economical. Recently, the government introduces the option to use gas engine or diesel using gas as fuel but in the reality, gas supply is hard to reach a lot of scattered islands. The government also tries to introduce solar photo voltaic (PV) and various kind of easily available renewable energy including wind, and micro hydro, but they are facing intermittency problem. Since the existing grid capacity in many small islands is limited, the capacity of PV and Wind that can be installed are limited and it need battery at least for stabilizer. Otherwise it must be installed as hybrid with a costly diesel power plant.

The government insists to achieve the Presidential policy to develop Indonesia from the outskirts by empowering regions and rural potential under national unity scheme. The government put the target to achieve 99 percent electrification ratio by the end of 2019 including 694 villages and 137 outer islands districts and isolated islands. However, according to the national electricity business plan the government still rely on the costly fossil fuel Diesel Plants and Mobile Power Plant to achieve the target. To address this problem, this study will propose LK initiative as an option to reach the isolated and remote rural areas. LK as a people way of electricity can be considered as a simple and eco-friendly way to attain 100 percent electrification ratio by utilizing waste and sun potential.

According to Electricity Law no 30/2007, Renewable energy is defined as the energy that can be provided by managing sustainable renewable sources including geothermal, wind, bioenergy, sun, runoff river, water fall, and ocean related power potential. As mentioned in the National Energy development plan (RUEN), only around 5% renewable energy of 29,544 MW potential has been utilized. Among those, only less than 10% of more than 80,000 MW hydro potential was developed while bioenergy is reported only less than 5% of 32,654 MW was developed and only around one percent of more than 200 thousand MW sun energy and 60 thousand MW wind energy potential been developed [5]. The government will also have high risk in the construction of large-scale hydro and geothermal power plants because the fact said that such a giant power plants often ended with long time delay due to non-technical problems including procurement, financing, permit processing, and land acquisition processing [1]. As seen on Table 1, the portion of small scale distributed renewable plants including Solar capacity in MWp, Biomass, biofuel, and coal gas are very limited.

| Type (MW)  | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | Total |
|------------|------|------|------|------|------|------|------|------|------|------|-------|
| Geothermal | 210  | 150  | 221  | 235  | 405  | 445  | 355  | 2537 | 20   | 5    | 4,583 |
| Hydro      | 66   | 287  | 193  | 755  | 315  | 196  | 635  | 4,461| 564  | 7,472|       |
| MicrHyd    | 108  | 202  | 366  | 103  | 31   | 811  |      |      |      |      |       |
| Solar (MWp)| 5    | 22   | 214  | 281  | 200  | 325  |      |      |      |      | 1,047 |
| Wind       | 70   | 60   | 5    | 45   | 10   | 30   | 300  | 60   | 589  |      |       |
| Biomass    | 53   | 53   | 41   | 19   | 235  | 10   | 411  |      |      |      |       |
| Total      | 512  | 774  | 1,040| 1,438| 996  | 871  | 1,299| 7,323| 20   | 639  | 14,912|

Table 1. Renewable Energy development plan 2018-2027
2. Related Works

2.1. Biomass Development Trend
The depletion of fossil fuels and its bad impact to the environment has motivated many countries to develop renewable energy that easily available around the community such as solar, wind, and biomass including waste. For example, the study regarding the use of residual biomass from various crops in Mexico was conducted by Martinez-Guido et al[6], who recommended to consider all the activities included in the supply chain since the collection of residues until the combustion of pellets in power plants. The study found that biomass is possible to fulfil about 50% of the national demand and reduced 25% of CO2 emission[3]. In other study, Gebreegziabher et al[7] depicted that the low cost of biomass makes it more beneficial compare to other renewable energy sources. Unlike those of fossil fuels, biomass can be presumed no carbon emission. The study proposed that biomass should be dried before using it for combustion in order to efficiency of power plant [4]. The study of potential biomass in Minas Gerais Brazil has been conducted by Teixeira et al[8] who proposed the geographical planning of biomass energy production to optimize the forest biomass used for power plants by locating the optimum number of power plants, which transport distances of raw material is minimum RUEN[5].

Techno-economic study of rice straw in Egypt had been conducted by Abdelhady et al[9] by simulation using System Advisor Model, reported the levelized cost of electricity (LCOE) of the average nominal (10.55 c/kWH) and the average real (6.33 ¢/kWh). This number is very competitive to the LCOE of other renewable energy. The study also found that LCOE affected by both internal and external factors. Internal factors such as flue gas temperature, rice straw moisture content and excesses fed air are affecting energy output. External factors including feedstock price and interest rate are sensitive to affect LCOE [10]. Other study depicts that biomass Combined Heat Power plants are only suitable for village and town systems with a relatively low population density [11].

Biomass power plant on hybrid with solar was studied by Sahoo et al[12], which is taking heat transfer fluid through parabolic trough collector (PTC) and remaining from biomass to maintain the steam at superheated state of 500 °C and 60 bar and supplied to turbine at steam mass flow rate of 5 kg/s. Habibollahzade et al[13], conducted study about integrated renewable energy plants in Teheran by exploiting the warm air of the condensers outlet into the Steam Coal Power Plant. Results indicated that by decreasing the humidity of the municipal solid waste (MSW) from 40% to 30% or by increasing MSW feeding rate (0.934–1.146 kg/s), the mass flow rate of the condenser cooling air increases from 190.3 kg/s to 233.7 kg/s. Results demonstrate that in the integrated system, by a 22% increase in the MSW feeding rate (from 0.934 kg/s to 1.146 kg/s) or by decreasing the MSW moisture content (from 40% to 30%), power output of the WTE plant and SCPP increases by 22% and 7%, respectively. In average, total energy and useful exergy efficiency of the proposed system is increased by 0.15% and 0.12% compared to the standalone WTE plant during nighttime.

2.2. Rural Electrification
Rural electrification is a big issue since there are still more than one billion people have no electricity and more than two billion people have unreliable electricity supply. This happens also in the developed nations. Access electricity to rural areas is a global issue that should be solved by all countries[14]. Until recently, most rural electrification program including in Indonesia are still using grid extension thru Medium Voltage and Low Voltage lines that may increase losses on the power grid. A study at Kanjikuzhi village in India, shows that Microgrid with additional renewable energy can reduce the average cost of electricity by 26%, diminish power interruptions by 40% and decrease grid losses by 62.5%, compared to a simple extension of the central power grid[15]. Rural electrification is the latest portion but the hardest part to attain a full range of electrification because the remaining houses to be electrified are usually isolated but scattered and some are located on small islands around the nation like those in Indonesia. Electrification ratio depends on people maturity. It was explained in one study that the electrification ratio is positively correlated with human development index. The components of the human development index are formed from life expectancy, average length of schooling, school life expectancy, and per capita expenditure. Human
development index, shows an increasing value although still below the average index of national human development of Indonesia [16].

Legino et al., depicted that the efficiency saving of large scale centralized and interconnected system has been decreasing due to the cost of delay because such huge projects often suffered from construction problems. To address the large scale dilemma, STT PLN has proposed the people way electrification system, namely ListrikKerakyatan, which adopting the concept of distributed generation using renewable energy available surround the community such as wind, solar, and waste micro power plant [1, 2, 11]. Although, the fact that the cost of distributed power generation and renewable technology such as solar PV are decreasing, national rural electrification planning including that of Indonesia remains ignoring distributed power generation[17]. The geographical condition of most rural electrification is typically isolated and the distance from house to house is far. It is plausible that despite of increasing trend to use of renewable energy sources, 40% of the new connections until 2030 will still use diesel generator that may be installed either as off-grid, to support grid extension, or as part of distributed generation plants in rural zones. The study shows that what kind of model depending on geographical, climatic and logistical factors, while benefits of the support to national grid extension strategy have been highlighted[18]. However, the big concern for diesel genset is a high price of fuel and its difficult fuel transportation to the isolated and scattered areas.

3. Rural Development Plan in RUPTL 2018 – 2027

According to National electricity business plan, the total number of households that have not gotten electricity are more than three million, as shown in Table 2. The plan shows that it requires around 59 thousand km of medium voltage lines (MV) and 54 thousand of low voltage lines (LV) to connect the new customers in rural areas to the existing networks. But there are still around 270 MW diesel or PV required to electrify the remote and isolated areas. Those rural development needs the total amount of fund around 9,400 million USD to install MV, LV, and its associated distribution transformers[4].

Table 2. Rural development plan toward 100% electrification ratio in Indonesia

| YEAR | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | TOTAL |
|------|------|------|------|------|------|------|------|------|------|------|--------|
| MV (KM) | 22,904 | 7,905 | 4,373 | 4,122 | 3,652 | 3,481 | 3,338 | 3,336 | 3,150 | 2,780 | 59,041 |
| CAPEX MV (MUSD) | 670.7 | 205.6 | 145.5 | 121.5 | 104.2 | 99.4 | 95.8 | 95.8 | 90.5 | 79.8 | 1,709 |
| LV (km) | 14,550 | 9,509 | 5,249 | 4,565 | 3,888 | 3,700 | 3,496 | 3,493 | 3,299 | 2,911 | 54,660 |
| CAPEX LV (MUSD) | 204.7 | 139.5 | 99.5 | 70.5 | 60.5 | 57.6 | 54.3 | 54.4 | 51.3 | 45.3 | 838 |
| TR. D (kVA) | 478,000 | 132,800 | 1,400 | 800 | 400 | 100 | 100 | 100 | 100 | 100 | 613,600 |
| CAPEX TRD (MUSD) | 1,079 | 800 | 1,302 | 420 | 310 | 120 | 100 | 90 | 90 | 60 | 6,111 |
| P PLANT (kVA) | 135,398 | 74,364 | 50,517 | 8,434 | 0 | 0 | 0 | 0 | 0 | 268,713 |
| CAPEX P PLANT (MUSD) | 182 | 352 | 185 | 25 | 0 | 0 | 0 | 0 | 0 | 744 |

4. People Way of Rural Development: Listrik Kerakyatan

ListrikKerakyatan (LK) is a model of electricity development by using simple small-scale plants using clean energy mix available surround the communities that should be built together and simulataneously by as many local people as possible [1, 2, 10]. There are five criterias of LK; first is simple, means small-scale (10 kW–100 kW) and using friendly technology. Second, clean, means that the energy mix must be dominated by renewable energy such as solar, biomass, wind, or hydro if available. Third, Fast, means that the construction time of the plants must be short (Solar PV, Small biomass, small Wind Power). Fourth is Self Sufficient or the owner of LK should be local people and its plants must use available equipment with as many local spare parts as possible. Lastly, “Gotong Royong”, this is the Indonesian term means togetherness. LK must be built as many as possible simulataneously by all communities [10, 11]. This idea was proposed by STT PLN, which has been implemented using the process, with a patent name TOSS. It is originally Bahasa stands for TempatOlahSampahSetempat (local waste processing unit). TOSS that produces pellet from fermented waste as renewable energy to run diesel generator thru gasifier can be owned and managed by local people using local shredder and pelet machine that can be made locally [1–3].
Conceptually, LK is adopting distributed generation that has flexibility to utilize small size renewable energy such as solar, wind and waste, which are available surrounding people. By this model, the government can give a chance to empower local people to involve in electricity development through Small and Medium Enterprise, namely UMKM [2]. LK will become sufficient rural electrification model for Indonesia because the electricity can reach any people who live in 3000 islands across the nation in a shorter time without necessarily waiting for the construction of interconnected distribution lines. Additionally, this model can give complementary solution to attain 100 percent rural electrification target as fast as we want to. LK provides also creative business opportunity as any local people may own and manage electricity by utilizing waste around them because the investment cost to build small size of 30 kW to 50 kW is relatively low [2]. Technically, LK will also reduce the transmission losses and the problem of excessive transformer overload and drop voltage [1, 3–5, 10]. Last but not least, LK can be an answer to the government target of having 23% of renewable portion in the national energy mix of 23% by 2025[1–3].

5. Conventional Distribution vs People Way of LK

5.1. Simulation Model
The objective of this study is to answer the question whether LK model as a people way of electricity development may give a better option to the conventional way of electrification using distribution lines to connect to the nearest existing electric lines. The method of simulation is using previous study conducted by Legino et. al, as shown in Figure 2[3], that compared the cost of electricity between the formal planned model and the people way of LK. Cost comparison is calculated by assuming that the total capacity of LK units is similar with the total capacity of the installed plan of transformer distribution. The total cost of conventional distribution consists of the investment cost of each associated Medium Voltage lines and Low voltage lines. The data for simulation is taken from previous study, which divide the specific costs based on three typical regional condition. First, NTT region represents the eastern part of Indonesia with many small islands; Second, Papua region represents the area with least electrification ratio in Indonesia; and third, West Java represents the region with a more developed communities such as those who live in Java island and other big cities in the islands of Sumatera, Kalimantan, and Sulawesi[3].
5.2. Specific Investment Cost of LK for 3 Regions
Legino research, revealed that the capital expenditure to install LK unit of 2x20 kW and for the unit size of 2x50 kW is presented in Table 2. The investment cost is divided into three different categories to reflect the different situations in each region. For example, The total investment cost (capex) for the developed area is represented by West Java is USD 59,212 for 2x20 kW and 113,854 for 2x50 kW. The cost for Papua and NTT is shown on Table 3.

Table 3. Capital expenditure of LK unit

| Unit Size                  | 2x20 kW (USD) | 2x50 kW (USD) |
|----------------------------|---------------|---------------|
| Gasifier                   | 15,600        | 28,100        |
| Genset                     | 25,200        | 45,400        |
| Control and Monitor        | 1,250         | 1,800         |
| LV lines cost of West Java | 17,162        | 38,614        |
| LV lines cost of NTT       | 37,756        | 84,951        |
| LV lines cost of Papua     | 22,825        | 51,357        |
| Total Capex West Java      | 59,212        | 113,854       |
| Total Capex NTT            | 79,806        | 160,191       |
| Total Capex Papua          | 64,875        | 126,597       |

Table 4. Specific Cost of MV, LV, and Distribution Transformer

| Region  | MV lines/kms (Mio USD) | LV Lines/kms (Mio USD) | Dist. Trf/kVA (Mio USD) |
|---------|------------------------|------------------------|-------------------------|
| National| 31                     | 17                     | 0.8                     |
| West Java| 28                     | 15                     | 0.7                     |
| NTT     | 37                     | 20                     | 0.9                     |
| Papua   | 62                     | 33                     | 1.52                    |

5.3. Potential Saving Calculation
The potential saving of capital expenditure (capex) is calculated by assumption that to attain 100 percent electrification ratio can be achieved if all rural areas are completely electrified. The simulated calculation is conducted through the following sequence:

- The cost of planned distribution lines is taken from national electricity business plan is the total investment cost for rural electrification nation wide
- The unit cost for distribution lines is grouped into three different typical areas; West Java, NTT, and Papua, as described in the previous section
The rural investment cost for each region is calculated using typical unit cost of distribution, which condition is similar.

It is assumed that the LK unit composition is 60% LK 40 (40 kVA capacity) and 40% of LK 100 (100 kVA capacity).

The total LK capacity in the area is equal to the total capacity of distribution transformers that will be replaced by LK units.

The final total investment cost is the sum of the remaining MV lines, LV lines, and distribution transformer cost plus the total investment cost of LK units that will replace the distribution lines.

LK capacity in each area is calculated by using this equation:

\[ LK_a = LK_{40} + LK_{100} = 0.4 \cdot T_d + 0.6 \cdot T_d \]  

(1)

where \( LK_{40} \) is the total number of 40 kW LK unit, \( LK_{100} \) is the total number of 100 kW LK units, and \( T_d \) is the total capacity of distribution transformer in each area.

The investment cost of LK:

\[ C_{LK} = LK_{40} \cdot p_{40} + LK_{100} \cdot p_{100} \]  

(2)

where \( p_{40} \) is the capex of 2x20kW unit of LK and \( p_{100} \) is the capex of 2x50 kW unit (the data is presented in Table 3).

The investment cost of distribution lines:

\[ C_{DL} = L_{MV} \cdot c_{MV} + L_{LV} \cdot c_{LV} + L_{TD} \cdot c_{TD} \]  

(3)

Where \( L_{MV} \) is the length of medium voltage lines, \( L_{LV} \) is the length of low voltage lines, \( L_{TD} \) is the capacity of distribution transformer, \( c_{MV} \) is the unit cost of MV lines, \( c_{LV} \) is the unit cost of low voltage lines, and \( c_{TD} \) is the unit cost of distribution transformer.

The total national investment cost of LK:

\[ CLK_n = \sum C_{LK} \]  

(4)

Where, \( CLK_n \) is Total National Investment cost of LK where it is the result from sum of Cost of all LK was built.

The total national investment cost of distribution lines:

\[ CDL_n = \sum C_{DL} \]  

(5)

Where, \( CDL_n \) is total national investment cost of distribution lines obtained from sum of all cost Distributed Lines was built.

**Table 5. Rural Electrification Capital Expenditure comparison: LK vs. Distribution lines**

| PROVINCIAL AREAS | \( L_{MV} \) MV length | \( L_{LV} \) LV length | \( L_{TD} \) | # of customer | LK 40 | LK 100 | \( C_{DL} \) Capex | \( C_{LK} \) Capex |
|------------------|-------------------------|------------------------|-----------|--------------|------|------|------------------|------------------|
| West Java        | 659                     | 546                    | 51810     | 390,262      | 259  | 414  | 62,909           | 62,529           |
| Banten           | 262                     | 2,820                  | 34730     | 116,487      | 365  | 97   | 73,947           | 32,664           |
| Central Java     | 335                     | 1,265                  | 40450     | 478,373      | 425  | 113  | 56,670           | 38,044           |
The national distribution lines is around 2.2 million USD. The total national investment cost of distribution lines:

\[ C_{DL} = \sum C_{DL} = 3,567.3 \text{ million USD} \]

From Table 5, it can be seen that the total unit of LK with 40 kW, LK_{40} is 37,420 units and LK_{100} is 10,322 units. The result can be summarized as follows: The total national investment cost of LK, CLK_n = \sum_{LK} = 1,341.4 million USD, the total national investment cost of distribution lines, CDL_n = \sum_{CDL} = 3,567.3 million USD. The result shows that the potential saving of capital expenditure to attain 100% rural electrification using LK model to replace the conventional distribution lines is around 2.2 million USD.

6. Conclusion

The study shows that financially, the initiative of Listrik Kerakyatan using briquette or pellet of TOSS local waste processing unit provide financial saving potential around 2.2 Million USD compare to the conventional rural electrification model using distribution lines. This saving has not counted the additional LK power plants. In addition, LK initiative provides social benefit as many local people may owned pellet business as well as electricity business. LK will also potentially reduce unemployment since all domestic waste can be processed in their own community, so there will be no more waste truck on the road. LK-TOSS will make no more methane gas from waste that deposit into landfill area.

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