Reducing coal consumption by people empowerment using local waste processing unit

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Abstract. Until the next following decades, energy mixed in Indonesia will be dominated by coal. Many studies assert that biomass can be used as coal substitution but it is not the case in the real world because the cost of biomass is still higher than the coal price. This study proposes the cheaper way of making biomass by using special method of local waste processing unit that has a patented name, TOSS. This kind of biomass, which was invented by STT PLN Jakarta, school of technology, is more economical than other biomass because waste as raw materials is much cheaper than other commonly used biomass like wooden forestry or agroplantations. Many cities in the world are solving their municipal waste problem by using large scale and high tech approach, which process is conducted in the landfill area. TOSS is using small scale and simple technology that can convert waste to become pellet by local people in its source. The pilot project at Klungkung showed that the pellet of TOSS can be used not only for cooking but also for diesel fuel substitution. This study will use that finding to show that TOSS pellet can also reduce coal consumption by mixing it with normal coal. The simulation is conducted by calculating the equivalent energy and capacity of waste energy from TOSS in term of coal equivalent under the context of Indonesia.

1. Introduction
Currently, Indonesia becomes oil and gas importer after several decades buoyed by its abundant oil and gas reserve. The only remaining fossil reserve is coal but it will be ended in 72 years, if the annual coal consumption remained as high as 400 million tons. The coal for power plant consumption until the year of 2023 is still more than 50 percent of energy mix. As shown in Figure 1, this number is not so much reduced from the current portion of 58.3%. If there is no special intention to utilize alternative energy, mainly renewable energy, it can be predicted that for the next following decades, more than half of national energy mix is composed by coal.
Many studies assert that biomass can be used as coal substitution but in the real world there are very limited countries that have policy to use biomass as coal substitution or boiler cofiring. The reason is that the cost of biomass is still higher than that of coal. To overcome those challenge, School of Technology Jakarta, STT PLN has conducted research and pilot project to convert fresh waste into pellet by empowering local people and local small enterprise. This model has a copy right logo and name of TOSS. The waste pellet processed by TOSS model is more economical than those of other biomass because waste is much cheaper than other biomass made from wooden forestry or agroplantations. Indeed, many cities in the world have applied various technology to solve their municipal waste problem by using large scale and expensive approach, which process is conducted in the landfill area.

TOSS converts waste into pellet in its source using small scale and simple technology that can be easily proceeded by local people. In less than ten days TOSS could produce pellet as biocoal with approximately 3000 kcal/kg. The pilot project at Klungkung showed that the pellet of TOSS can reduce 80% of diesel consumption. This study will use that finding to show that TOSS pellet can reduce coal consumption by mixing it with normal coal. The simulation is conducted by calculating the equivalent energy and capacity of waste energy from TOSS in the context of Indonesia compare to that of coal.

2. The purpose of the study
This study will conduct simulation to calculate the national waste capacity and energy potential in term of coal energy equivalent, by calculating the coal equivalent energy and capacity of waste to become TOSS pellet in the context of Indonesia. The potential waste energy will be estimated using national municipal waste data from the official documents. The result can be used to show that TOSS pellet can reduce Indonesia coal consumption by mixing it with normal coal that commonly be used for coal fired power plant. As shown on Figure 2, the annual coal consumption of Coal Power Plant (CPP) in Indonesia is around 100 Million ton. If all CPP mixes its coal with at least one percent biomass, the country may have potential saving of one million ton of coal per year. What should be done by the government is to establish policy that any used of coal for industry must be mixed by certain percent of biomass as have already applied in several countries.

Figure 1. Indonesia Energy Mix Policy

Figure 2. Coal Consumption Estimation
3. Previous Study

3.1. Coal as a largest fossil fuel potential
Coal is the largest available reserve of fossil fuel which was formed from the plants decomposition that has a high energy potential. Therefore, until recently, coal is still highly consumed for both electricity generation and heating purpose [1]. Coal was getting energy from the sun, which was then stored in the dead plant for several hundred million years [2]. The older the coal maturity, the higher the energy content. The highest caloric value of coal is Anthracite (31-36 MJ/Kg), followed by Bituminous (25-34 MJ/Kg), Sub-bituminous (19-30 MJ/Kg), and the lowest is Lignite (12-19 MJ/Kg). According to US based, Lazard’s levelized cost of energy (LCOE) analysis version 12, the lowest LCOE of power plant is Gas Combined Cycle ($41-$74) and coal is the second lowest with LCOE on the range of $60 to $143[3]. However, many countries are still relying on coal as the fuel for power plants as its reserve is abundant. Coal exhibits a 109 year reserve to production ratio, means that from today, coal will be lasted in the next hundred years [4]. Nevertheless, if the coal consumption is remain increasing from year to year, its deposit will be lasted in less than a hundred years. Therefore, there should be a collaborative effort among countries that highly exploite coal to reduce its consumption by mixing it with renewable bioccoal, as an option that will be presented in this study.

3.2. Waste to energy
The energy potential of waste has become attention of many researchers. One of those is McKendry who examined the potential of a restored landfill site to act as a biomass source. He asserted that like other purpose-grown biomass, waste biomass is also potentially economical for power generation [5]. Waste, particularly municipal waste will create problem to both the people and the environment. Originally, people treat their waste by either burning it into incenerator or take a cheaper way by throwing the waste away to landfill site. But, currently, many big cities in Indonesia including Jakarta, Bandung, Denpasar, Medan and other high populated towns in Indonesia are facing a problem of limited landfill space. As an option, there is new approaches to treat municipal waste by converting trash into energy, namely waste-to-energy (WTE) that may leave mass-burn incineration method. Waste to energy (WTE) is a terminology commonly used to describe the conversion of waste by-products into energy such as steam-generated electricity [6].

The most common model of WTE includes gasification, plasma gasification, and pyrolysis, which are potentially cleaner in emissions and provides more flexible end product in terms of energy output. WTE could eliminate landfiling used because waste can be consumed directly in term of thermal or electricity. Among those approaches, if the main purpose is to produce electricity, so far any combustion-based systems is better. But if the main goal is to strongly reduce waste material that should be sent to landfill, the best way is gasification [7]. However, municipal wastes are by nature very heterogen that can make it hard to be used for power plants without assessing its materials. Assesment is needed to sort which material is sufficient for instance, recycling, composting, reducing, or redesigning. However, WTE technologies are still facing economic challenge because this process is challenged by some problems including operational inexperience, high costs, lack of financing, and concerns about toxic emissions.

3.3. TOSS: Local waste processing unit
Recently, a new invention of waste treatment that can be carried out by ordinary people in their own communities was declared by the School of Technology in Jakarta, STT PLN. This local waste processing unit has a copy right name, TOSS, which logo was patented as shown in Figure 3. TOSS is originated from Indonesian language, like for instace the Japanese original name for Kaizen in management field or Osaki in the waste treatment field.
Figure 3. TOSS Logo and its unique characteristic of waste to energy model

Although there have already some waste to energy methods including incenerator, digester, gasifier, and pyrolysis, such technologies are still challenged by several problems including high capital expense and the large required processing area, which is usually conducted in the landfill [9],[10]. For example, there are at least two projects, one in Bali and another in Bekasi, that were failed because the process was depending on available methane gas from landfill, while in reality was not sufficient. Even worst, such digester concept could not solve the piled of remaining waste because it took only the gas produced by organic waste, not the solid waste. As the intention to solve municipal waste problems in many big cities, around two years ago, the government of Indonesia declared large scale waste to energy projects to convert waste in the landfill to become electricity in 12 big cities. But until recently, none of those expensive projects have been started, because PLN as off-taker company has not agreed to the price offered by the investors. Similarly, the local governments are also reluctance to the proposed tipping fee.

Actually, TOSS as a simple and people friendly way of local waste treatment unit can be used as an alternative to solve that problem [11],[12],[13]. As shown in Figure 1, the TOSS process begins with collecting valuable waste such as bottle, box, and can that has valuable selling price that can be sold for additional income. Then, put the waste into 2m x 1m x 1m bamboo container and spray it layer by layer using special made bioactivator to reduce waste moisture, waste odor, and to create increased calory. After the bamboo box full, then cover it by plastic sheet and keep it for about a week and control the waste temperature to comfort the bacteria (should be more than 40°C but could not exceed 70°C).

After 3 days the waste has already died, no more odor and the volume will be reduced about half, but keep it in the bamboo until 7 to 10 days before crushing it using shredded machine. The shredded waste is then screened before put it into briquette machine. Now the pellet or briquette is ready to be used as biocoal for the heating or electricity generation purpose. The TOSS pellet has been tested several times in the laboratory and reported that the gross calorific value of the TOSS pellets are vary around 2800 to 3200 kcal/kg.
Figure 4. TOSS process at Pondok Kopi and Duri Kosambi

STT PLN has undertaken pilot project of TOSS at Pondok Kopi and Duri Kosambi Jakarta and since January 2018, TOSS has been implemented at Klungkung District. The project has successfully generated electricity using 15 kW Yanmar diesel genset and 30 HP Trilion gasifier feeding by TOSS pellet produced by Klungkung village people. Unlike previous way that must send waste to the landfill, TOSS can treat municipal waste in their own place. Therefore TOSS can eliminate the frequency of waste truck to the landfill. In addition, TOSS is different from other small scale waste treatment that needs to separate organic and non organic waste, TOSS needs no preliminary sorting and can solve the plastic and other non organic could process the whole mix waste.

3.4. Benefit and cost of TOSS
In their study, Legino and Arianto depicted that the unit size of TOSS is maximum 10 ton of waste per day because TOSS is dedicated for local people and affordable by the small and medium enterprise [13]. The investment cost of the smallest unit of TOSS (3 ton of waste per day) is USD 74,360 and the annual operational cost is USD 14,435. This unit can produces 144 kWh energy per day. For the largest unit of 10 ton of waste per day, the investment cost is USD 223,156 and its associated operational expenditure is USD 47,546 per day, that may potentially produce 1440 kWh of electrical energy [13].

TOSS provides intangible benefit in the form of social benefit and environmental benefit. Social benefit can be earned from people opportunity to get income and wellbeing improvement under the zero waste milieu. Environmental benefit can be valued from fossil fuel cost saving and carbon reduction.

4. Potential Waste Energy calculation
This study is a case study analysis by using simulation to calculate the possible energy amount that can be produced by TOSS model to reduce the exploitation of coal. The cost and benefit of TOSS then compared to that of coal. The primary data is taken from the pilot project of TOSS that have been conducted at three locations, Pondok Kopi, Duri Kosambi, and Klungkung areas. The secondary data is taken from a formal document including Electricity Business Plan, Statistic Book published by government institution such as Ministry of Energy and Mineral Resources, PLN State owned enterprise for electricity, and Central Statistic Bureau (BPS).
4.1. Data
Selected data for related fuel prices are taken from National Electricity Business Plan 2018-2027 as follows:
- Sub Bituminous coal (5200 kcal/kg) with the price of USD 70 per ton,
- Lignite coal (4400 kcal/kg) is USD 50 per ton
- Low rank coal at mine mouth (<3800 kcal/kg) is USD25 per ton.
- Diesel fuel HSD is USD 0.5 per liter (9100 kCal/litre)
- LNG is USD 10 per liter (252,000 kcal/Mscf)
- 1 kG of pellet produces 1 kWh energy

4.2. Municipal waste energy potential in Indonesia
The main data that will be used in this study will taken from the statistic book of New and Renewable energy, Ministry of Energy and Mineral Resources, including the landfill capacity along with its energy potential and the city population in each town. However, in reality, there are still a lot of waste that could not be sent to landfill, so there will be additional waste potential as well as its energy potential that can be calculated from the city population, as summarized below [6].
- The national population is 253 million people
- The total capacity of landfill around the country is 8,42 million ton per year.
- The breakdown data for each city can be see in Table

The capital expenditure and operational expenditure of a full cycle of TOSS process, from raw waste to become pellet up to generating energy are taken from previous study based on direct observation from the pilot projects as described above [12],[13].

The simulation is calculated with the follows:
- One ton of mixed municipal waste can be converted to 200-300 kg pellet
- The calorific value of 3000 ± 200 kCal/kg.
- For the purpose of this simulation, we put pellet production factor (p) = 0.25, means one ton of waste can produce 250 kg pellet
- The pellet calorific value that will be used for calculation, c = 3000 kCal/kg.
- To calculate the amount of energy, this simulation will use the average value that observed during implementation of TOSS at Klungkung, which is 1 kg of pellet may produced around 1 kWh electrical energy.
- Electricity efficiency generation (h_e) is assumed 0.6
- The waste to energy potential can be calculated as follows:

$$E_a = p \times W \times h_e$$

where Ea is annual energy potential in MWH, W is a raw waste volume in ton, and h_e is the electricity efficiency.

4.3. Landfill energy potential
As an example, let us calculate energy potential from Jabar area landfill. If we assume that all wastes in landfill will be converted into electricity, than the estimated energy potential $E_a = p \times W \times h_e = 0.25 \times 1,866,000 \times 0.6 = 279,900$ MWH per year. The power plant capacity can be calculated by using this formula: $P = E_a/(H \times 360)$; where P: electrical capacity in MW, Ea is annual energy potential in MWH, H is hour of operation per day (6 hours for peaker, 24 hours for base load). If the plant is used for base load 24 hours, the capacity is : $P = 279,900/(24 \times 360) = 32$ MW. If the plant is used as a peaker, than the potential capacity is: $P= 307,890/(6x360) = 130$ MW. The potential capacity of the rest areas are presented in Table 1.
Table 1. Landfill Waste capacity in Indonesia

| AREA     | Population | W (ton/yr) | Pellet (ton/year) | Ea/yr (MWH) | P base 24 hr (MW) | P peak 24 hr (MW) |
|----------|------------|------------|-------------------|-------------|------------------|------------------|
| JABAR    | 47.38      | 1,866,000  | 466,500           | 279,900     | 32.4             | 129.6            |
| DKI      | 10.28      | 1,643,000  | 410,750           | 246,450     | 28.5             | 114.1            |
| BANTEN   | 12.2       | 207,000    | 51,750            | 31,050      | 3.6              | 14.4             |
| JATENG DIY | 37.74   | 955,400    | 238,850           | 143,310     | 16.6             | 66.3             |
| SUMBAGUT | 24.46      | 589,780    | 147,445           | 88,467      | 10.2             | 41.0             |
| BALI NTB | 9.1        | 517,300    | 129,325           | 77,955      | 9.0              | 35.9             |
| NTT      | 5.2        | 15,050     | 3.763             | 2.258       | 0.3              | 1.0              |
| MALUKU   | 2.9        | -          | -                 | -           | -                | -                |
| SULUT    | 3.59       | 83,680     | 20,920            | 12,552      | 1.5              | 5.8              |
| SULSEL   | 9.91       | 182,500    | 45,625            | 27,375      | 3.2              | 12.7             |
| KALBAGUT | 4.17       | 192,080    | 48,020            | 28,812      | 3.3              | 13.3             |
| KALBAGSEL| 11.47      | 227,220    | 56,805            | 34,083      | 3.9              | 15.8             |
| PAPUA    | 4.1        | 10,490     | 2.623             | 1.574       | 0.2              | 0.7              |
| RiaU     | 8.53       | 363,180    | 90,795            | 54,477      | 6.3              | 25.2             |
| SUMBAGSEL| 23.13      | 335,290    | 83,823            | 50,294      | 5.8              | 23.3             |
| JATIM    | 39.08      | 1,237,010  | 309,253           | 185,552     | 21.5             | 85.9             |
| **TOTAL**| **253**    | **8,424,980** | **2,106,245**    | **1,263,747** | **146,3**       | **585,1**       |

4.4. Non landfill waste capacity estimation

Actually, not all municipal waste can be put into the landfill area and some of them are thrown into the water way, street, and any places. Every human create around 0.5 kg waste, so we can estimate the total waste volume in any provences and for the purpose of simulation of this study we put 0.4 kg waste per person per day. A non land fill waste estimation is calculated by subtracting the landfill waste from the estimated total waste in each provence.

Table 2. Non-Landfill Waste capacity in Indonesia

| AREA     | Popul. Million | Waste pot. ton/year | Landfill ton/year | non LF ton/year | Pelet prod. ton/year | Ea/yr MWH | P 24 hr MW | P pk 6hr MW |
|----------|----------------|---------------------|-------------------|-----------------|----------------------|-----------|------------|-------------|
| JABAR    | 47.38          | 11,845,000          | 1,866,000         | 9,979,000       | 2,494,750            | 1,496.80  | 173.2      | 693         |
| DKI      | 10.28          | 2,570,000           | 1,643,000         | 927,000         | 231,750              | 139,050   | 16.1       | 64.4        |
| BANTEN   | 12.2           | 3,050,000           | 207,000           | 2,843,000       | 710,750              | 426,450   | 49.4       | 197.4       |
| JATENG DIY | 37.74       | 9,435,000           | 955,400           | 8,479,600       | 2,119,900            | 1,271,940 | 147.2      | 588.9       |
| SUMBAGUT | 24.46          | 6,115,000           | 589,780           | 5,525,220       | 1,381,305            | 828,783   | 95.9       | 383.7       |
| BALI NTB | 9.1            | 2,275,000           | 517,300           | 1,757,700       | 439,425              | 263,655   | 30.5       | 122.1       |
| NTT      | 5.2            | 1,300,000           | 15,050            | 1,284,950       | 321,238              | 192,743   | 22.3       | 89.2        |
| MALUKU   | 2.9            | 725,000             | -                 | 725,000         | 181,250              |           |            |             |
| SULUT    | 3.59           | 897,500             | 83,680            | 813,820         | 203,455              | 122,073   | 14.1       | 56.5        |
| SULSEL   | 9.91           | 2,477,500           | 182,500           | 2,295,000       | 573,750              | 344,250   | 39.8       | 159.4       |
| KALBAGUT | 4.17           | 1,042,300           | 192,080           | 850,420         | 212,605              | 127,563   | 14.8       | 59.1        |
| KALBAGSEL| 11.47          | 2,867,500           | 227,220           | 2,640,280       | 660,070              | 396,042   | 45.8       | 183.4       |
| PAPUA    | 4.1            | 1,025,000           | 10,490            | 1,014,510       | 253,628              | 152,177   | 17.6       | 70.5        |
| RiaU     | 8.53           | 2,132,500           | 363,180           | 1,769,320       | 442,330              | 265,398   | 30.7       | 122.9       |
| SUMBAGSEL| 23.13          | 5,782,500           | 335,290           | 5,447,210       | 1,361,803            | 817,082   | 94.6       | 378.3       |
| JATIM    | 39.08          | 9,770,000           | 1,237,010         | 8,532,990       | 2,133,248            | 1,279,949 | 148.1      | 592.6       |
| **TOTAL**| **253**        | **63,250,000**      | **8,424,980**     | **54,825,020**  | **13,706,255**       | **8,124,003** | **940.3** | **3.761.1** |
For instance, the total waste of Jabar provence is 0.4 multiply by the population of 47,38 million people equal to 11.845 million ton per year. Non landfill waste volume is calculated by substracting the landfill volume from the total waste volume or 11.845 million ton minus 1.866 million ton equal to 9.979 million ton waste per year or 2.495 ton pellet per year. With $h_c = 0.6$, the energy potential is 1.496 GWH. It can be used for base power plant with capacity of 173.2 MW or as peaker 6 hour power plant with capacity of 693 MW. The rest calculation for the whole areas are presented in Table 2.

4.5. TOSS pellet as coal substitution

The potential saving of coal consumption by waste pellet substitution will be calculated by using an equal value of lignite as a lowest rank of coal. For the purpose of this study simulation, the lignite calorific value will be put on 3800 kCal/kg. If we take an average calorific value of TOSS pellet as 3000 kcal/kg, then any kg of coal is similar to 3800/3000 kg of coal, or TOSS pellet to coal ratio ($p$) is 1.3. From the power plant company point of view, TOSS pellet is still economical if the price of 1.3 ton pellet is below the price of 1 ton of coal price. For example, if the price of low rank coal is USD 300 per ton, than the pellet should be around 300/1.3 x USD300 =USD237/ton.

Estimated revenue can be taken from selling pellet, tipping fee, and selling valuable waste such as bottle, corrugated paper, etc. Revenue from selling pellet can be calculated as follows:

$$R = W \times p \times t;$$

where $R$ is revenue in USD, $W$ is waste weight in ton, $p$ is waste to pellet factor, and $t$ is the pellet price in USD. For the purpose of simulation we use the package of 3 ton of waste with $p = 0.25$, and $t, _{USD30/ton}. TOSS owner is still getting revenues from tipping fee that relatively lower than the existing waste management cost in each region. If the tipping fee is USD 7 per ton, than the local business company still enjoy around 17% IRR, higher than its used discount rate (10%). It means that TOSS pellet could potentially be used as coal substitution and could potentially reduce the coal exploitation.

5. Practical implication

5.1. Coal potential saving by using TOSS pellet

If the whole waste from landfill can be converted to pellet using TOSS process, the annual coal saving potential can be calculated as follows.

- The annual pellet potential as seen in Table 1 is 2,106,245 ton , rounded to 2 million ton
- Pellet to coal ratio ($p$) is 1.3
- The annual coal potential saving from landfill waste is 1.54 million ton coal equivalent

Similarly if the non landfill waste included (Table 2), the annual pellet production is 13.7 ton or coal equivalent potential saving will be 10.5 ton coal equivalent.

5.2. Other potential benefit of TOSS

If the government of Indonesia applies TOSS concept across the country, than the coal consumption will be reduced around 100 million ton per year. The coal consumption projection based on national business plan (RUPTL) 2018-2027 as shown in Figure 1 can be reduced as presented in Figure 5. In other words, the national coal reserve will be lasted longer if the government applies TOSS as the way of waste to energy model in every cities.

By applying TOSS in the whole nation as cofiring for any use of coal, the government can accomplish the target of 23% Renewable Energy (RE) of the national energy mix faster than the target of 2023. For example if 5% cofiring policy can be applied, it is similar to build RE plants that can produce 5 GWH of RE annually, equivalent to around 700 MW of Hydro Power Plant.
6. Conclusion
Since the process of making biocoal pellet by TOSS process can be undertaken simultaneously by ordinary people across the country, this study shows that TOSS can potentially save coal consumption around 10 million ton equivalent per year. In other words, TOSS may potentially save coal usage for power plan around 100 million for 10 year as the period of the national business plan. TOSS is also beneficial for environment, since it may save fossil fuel reserve for the next generation and reduce the methane gas emission that could harm the Ozone. In addition, TOSS provides social benefit as it may create opportunity for local people to run small business to produce pellet from domestic solid waste. Last but not least, TOSS may create clean and fresh neighbourhood since there will be less waste truck come and go from communities to the land fill.

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