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Submission date: 30-Nov-2022 11:24AM (UTC+0700)
Submission ID: 1966923778
File name: pen_Access_proceedings_Journal_of_Physics__Conference_series.pdf (582.72K)
Word count: 3185
Character count: 16347

IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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To cite this article: D I Mustia *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **896** 012063

Analysis of waste composition as a source of refuse-derived fuel in Cilacap

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Abstract. The government focuses on converting garbage into energy, such as in Cilacap, that waste is processed into Refuse Derived Fuel (RDF). Compared to organic waste, a material with high calorific value fractions such as plastic is a potential energy source. Of contrast, organic waste dominates the waste composition in Indonesia. This study aimed to look into the waste composition in Cilacap as a resource of RDF. This is descriptive research that uses quantitative approaches. Organic waste dominated composition by 53,14%, according to a survey of 100 respondents. The percentages of plastic waste, paper, textile, and rubber/leather are 28,46%; 16,09%; 0,8%; and 0,42%; respectively. People who generate more organic waste are more likely to engage in social activities, have no yards and have no livestock. Furthermore, buying too much food and regularly leaving meals on the table may increase organic waste production. The calorific value obtained from the data is 3.735 kcal/kg. Knowing the theoretical calorific value of waste composition in Regency gives an overview of economic potential and research into appropriate policy recommendations for the government.

1. Introduction

Open dumping and sanitary landfills are common waste management strategies used in Indonesia and Cilacap. This is located on the densely populated Java island. Its regency has four nearly full landfills. One of the landfills, located in Jeruklegi, holds around 120 tonnes of municipal solid waste (MSW) daily. In 2016, the landfill capacity in Jeruklegi reached overload, with an extension period until 2018. The costs of landfill degradation, such as leachates, greenhouse gas emissions, and the impact on residents' health [1], are a heavy consideration. *Peraturan Daerah Kabupaten Cilacap Nomor 3 Tahun 2011* aims to improve public health and environmental quality while turning waste into a resource. One possibility is to convert waste into refuse-derived fuel (RDF) [2].

RDF is a fuel derived from the solid combustible waste fraction of municipal solid waste (MSW) such as plastic, wood, pulp, or organic waste, other than chlorinated materials [3]. Organic waste makes up the majority of Cilacap's present waste. Organic waste has a calorie fraction of around 1.446 kcal/kg, compared to plastic, with a high-calorie fraction of up to 8.000 kcal/kg. Due to combustion, household kitchen waste reduces the amount of material that can be restored and increases operational costs [4]. Kitchen waste is an important parameter to consider when evaluating the feasibility of various disposal options, such as using direct composting land, stockpiling, or combustion. In some countries, waste sorting is widely used for material energy recovery and the production of waste-derived fuels.

IOP Conf. Series: Earth and Environmental Science **896** (2021) 012063 doi:10.1088/1755-1315/896/1/012063

Several studies have found a correlation between waste composition and the calorific value of RDF. Based on the existing waste composition in Singapore, RDF was produced using 42% plastics, 41% paper/cardboard, 7% textile, and 10% horticulture waste. It had a calorific value of 5.688 kcal/kg [5]. Then there is waste composition in Latvia and Lithuania consist of 16,5% paper and cardboard; 38,6% plastics; 3% biological waste; 2% fine; 21,9% nappies; 12,2% textiles, 2,5% rubber-leather, 2% wood and the rest is other. It has a calorific value of 4.392 kcal/kg [6]. The goal of this research is to look at the waste composition in Cilacap. Combustible solid wastes such as plastic, paper, textiles, rubber/leather, and organic waste were identified as potential RDF resources. This issue was intended to emphasize the importance of waste regulation, especially organic waste, the largest amount. The economic potential is defined by the profit of coal to RDF conversion usage.

2. Methodology

2.1. Study area description

Cilacap is in Central Java, Indonesia, and is bordered by the Indian Ocean. Cilacap Regency is divided into 24 districts, whose center has large industries such as power plants and the cement industry. Industries could be off-takers for RDF products, so it is very appropriate if Cilacap becomes a pilot project for waste management into RDF.

The study was conducted only in 5 of 24 districts total. There are Cilacap Utara, Cilacap Tengah, Cilacap Selatan, Kesugihan, and Jeruklegi. These five districts sent their waste to be processed into RDF at the beginning of the project. Waste resources from various sectors, including domestic waste, industry, markets, and other locations, are not taken into account. Only waste composition from household waste was identified in this study.

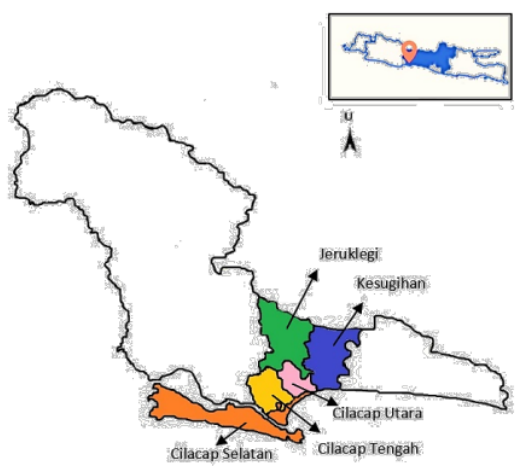

Figure 1. Study area.

2.2. Data collection and classification of solid waste

This study uses descriptive statistics. The composition of waste and theoretical calorific value of RDF were the variables investigated. Determination of samples for total respondents using the solving formula by using cluster sampling. This cluster is divided into 3 categories; there is Residential Cluster (C1), Non-Residential Cluster (C2), and Rural Cluster (C3). According to Isaac and Michael [7], sampling error could be used 10%, and a sample of 99,98 is rounded up to 100 respondents.

Calculation of theoretical calorific value is based on the following formula:

$$CV_{Theoretical} = TS \times Ref.CV \quad (1)$$

Where,

$CV_{Theoretical}$ is the theoretical calorific value (kcal/kg),

TS is waste generation/total waste (kg/kg), and

Ref.CV is calorific value reference (kcal/kg)

People in Cilacap Regency generally put their waste in a trash can placed in front of their house, with no additional components to protect the waste from hot sun and rain. Depending on the timetable of waste officers' transportation, waste collection in front of each residence is formed in one week or less. This condition has an impact on the waste moisture content created. The survey only identified waste such as plastic, paper, textile, rubber/leather, glass, metal, and organic waste. The amount of glass and metal waste is not included in calculating theoretical calorific value because they are separated in management.

3. Results and discussion

3.1. Waste composition

Figure 2 shows the total amount of solid waste generated in Cilacap's five districts. In general, organic waste dominates the composition, which is 53,14%. Plastic and paper come in second and third place, with 28,46% and 16,09%, respectively.

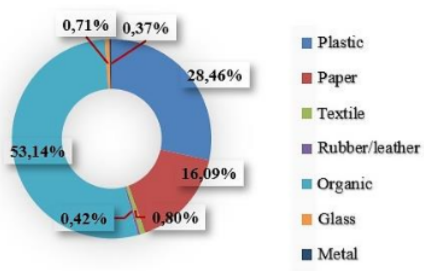

Figure 2. Household waste composition in Cilacap.

The household waste generated over a week is divided into three clusters. The result of determining the waste composition of each cluster, figure 3 shows that the Residential Cluster (C1) has the highest organic waste content of 62,4%, compared to the Non-Residential Cluster (C2) and Rural Cluster (C3), which have 57,73% and 46,18% organic waste, respectively. People in C1 are driven to discard all their organic waste without treatment due to landless housing design. The most common waste materials are plastic and paper, which account for 18,06% and 16,67% of waste, respectively.

C2 and C3 generate most plastic waste since their homes have land for organic waste disposal, such as composting and biopore. People in C3 frequently give their leftover food to livestock, such as chickens, ducks, and catfish. People also believe that non-biodegradable waste, such as plastic, should be processed. C1 residents, on the other hand, prefer to use it for crafts such as plant pots and decorations.

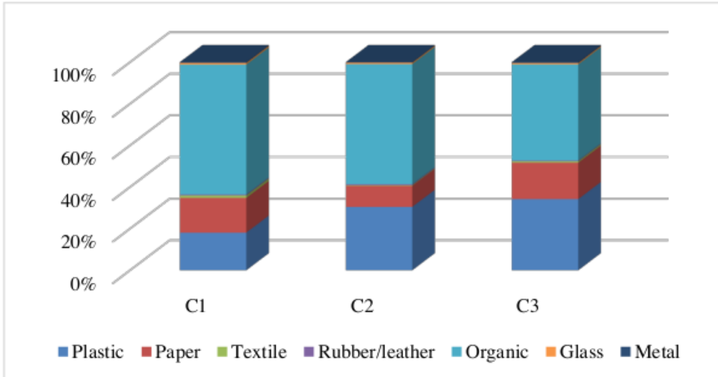

Figure 3. Waste composition for each cluster.

During the COVID19 pandemic, tissue was frequently used by the public then discarded as paper waste, notably by people with flu symptoms. In addition to becoming used to a cleaner lifestyle that the community has begun to apply, the activity tends to use more tissue as a cleaning item because it is seen as more practical than rags [8]. Residential clusters are also more inclined to purchase things packaged in paper, resulting in increased paper waste.

Waste generated by community activities cannot be described by a single behavior but by a mixture of actions that might increase or decrease the amount of waste produced. As a result, the outcomes of waste management by people's behavior leave the waste generation recorded. The amount of waste generated is determined by the level of public consumption in their activities.

The type of organic waste produced by people who live in housing with those in single houses with significant land has different types of organic waste. Residential cluster (C1), whose dominant houses have been paved and have no land for woody trees, generally organic waste in the form of leftover vegetables, fruit, and food [9]. The amount of waste produced is also influenced by the social life of the environment, as people with strong social ties are more likely to entertain guests and consume more food [10]. This triggers the production of organic waste and increases plastic and paper waste generated by packaged goods. Meanwhile, the organic waste of rural clusters (C3) with extensive amounts of land and woody plants in their yards is primarily leaves and grass.

From the survey results that people rarely dispose of textile and rubber/leather types of waste. Most stated that they would donate their clothes, bags, shoes, or sandals to other people before they were damaged, not included in the waste generated. People will only throw away items that are no longer suitable for use.

The main determinants of waste disposal behavior come from recycling attitudes, previous recycling experiences, concern for the environment, and the consequences of recycling [11]. Increased awareness, according to Comber [12], leads to self-reflection and re-evaluation. When people are re-evaluated, they experience guilt because they notice alterations in their attitudes and behaviors. The existence of public perceptions related to environmental health motivates people to manage their waste more wisely [13].

According to Maryono and Fitriansyah [14], the most optimal reduction of waste entering the landfill in Pangkalpinang City is achieved by the C scenario based on 3R. This approach has the potential to reduce waste transported to landfills by 29,65%. The percentage of household waste reduction based on the 3R program had reached 48% by the conclusion of the simulation year. Because the quality of excess organic waste with porous biomass in kitchen waste is poor and the calorie fraction is low, regulating the amount of organic waste produced is required. In this situation, a rule is required to decrease the amount of waste that has gotten out of hand while also increasing the efficiency of the RDF energy resource.

Activities in the Cilacap Regency community that can reduce waste generation are by sorting, being active in 3R, garbage bank program, having biopore holes, and making compost from organic waste. The Cilacap Regency Government needs to make processing policies or regulations for the particular transportation of organic waste so that organic waste generation is not too high.

3.2. Calorific value and economic potential

Most of the energy resource was derived from coal. Meanwhile, in Cilacap, waste-derived energy is not being used to its full potential. When the potential of waste can be maximized, it has economic value. As an alternative resource, RDF calorific value produced for burning becomes an economic value.

The theoretical calorific value is calculated from community questionnaire data regarding the composition of the waste generated. Based on the calorific reference value, the theoretical calorific value is approximately 3.735 kcal/kg. This value is obtained from multiplying waste composition from the survey results with the reference caloric value. More detail can be seen in **Table 1**.

Table 1. Calorific Value (CV).

Calorific value reference (kcal/kg)		Mass (kg)	$CV_{Theoretical}$ (kcal)
Plastic	8000[a]	121,615	972.917
Paper	3588[a]	68,742	246.647
Textile	5200[a]	3,417	17.771
Rubber/leather	7200[a]	1,810	13.034
Organic	1446[b]	227,050	328.314
Total		422,634	1.578.683
$CV_{Theoretical}$ (kcal/kg)			3.735

[a]Dong *et al* [15]
[b]Subramanian [16]

The theoretical calorific value is calculated by the formula (1) for $CV_{Theoretical}$, from a survey related to the composition of waste generated. The calorific value reference is multiplied by the mass of waste for each type, resulting in a total value of 1.578.683 kcal. This value is divided by a total mass of 422,634 kg, then obtained $CV_{Theoretical}$ around 3.735 kcal/kg.

The composition of waste in Europe as a material of RDF are 16,68% food and gardening waste; 3,25% wood; 32,15% paper and cardboard; 22,19% plastic, 1,13% tetra brick; 9,32% textile; 0,60% rubber/leather; and the rest is other. It produces a calorific value of around 5.101 kcal/kg. RDF in Singapore is also produced from 42% plastics, 41% paper/cardboard, 7% textile, and 10% horticulture waste. It had a calorific value of 5.688 kcal/kg [5]. Then there is waste composition in Latvia and Lithuania consist of 16,5% paper and cardboard; 38,6% plastics; 3% biological waste; 2% fine; 21,9% nappies; 12,2% textiles; 2,5% rubber-leather; 2% wood and the rest is other. It has a calorific value of 4.392 kcal/kg [6]. Organic material, particularly kitchen waste, should be used minimally in RDF processing because it has a low calorific value. It will be more successful in increasing the calorific value of RDF if organic waste is reduced to less than 50% of the total and replaced with high-calorie materials.

Table 2. Estimated Difference Cost of RDF and Coal.

	CV (kcal/kg)	Energy requirement (kcal)	Mass (tonne)	Price per tonne (USD)	Total annually (USD)
RDF	3.735	205.425	55,00	20,76	$406.480,80
Coal	6.322	205.425	32,49	100,33	$1.160.460,92
				difference	$753.980,12

This value compares the cost of fuel purchases to determine the total cost of consumption. The quality is equivalent to the calorific value of coal of 6.322 kcal/kg and a price of USD 100,33 per tonne [18].

Coal mass which generates the same amount of energy to 55 tonnes of RDF per day, is 32,49 tonne. Each tonne of mass is multiplied by the RDF and coal prices. RDF price of USD 20,76 is the selling price of RDF in Cilacap. According to the results, the difference between RDF and coal is worth USD 753.980,12/a. When compared to coal, the advantage of using energy from waste recovery might save off-takers nearly half of their fuel expenses. However, the cost of maintaining RDF is not considered, so it is not easy to estimate profit for producers.

The government must implement a waste collecting policy to maximize the economic potential of waste energy recovery. This is to ensure that organic waste could be decreased, shallow calorific kitchen waste. Waste transported to be processed should be prioritized as much as feasible for waste with a high calorific value fraction, such as plastic and rubber/leather.

4. Conclusion

This research aims to estimate the composition of municipal solid waste in the Cilacap Regency in 2021. The pandemic COVID19 is ongoing this year. House characteristics and lifestyles have an impact on the amount of waste generated by each cluster. The estimated compositions of organic waste, plastic, paper, textile, and rubber/leather are 53,14%; 28,4%; 16,09%; 0,8%, and 0,42% respectively. The organic waste composition should be limited so that the calorific value of RDF can be maximized in order to enhance economic potentials. For the same energy estimate, the difference between purchasing RDF fuel and coal is USD $753.980,12/a. This profit is aimed at takers.

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