Landfill mining dominated by organic solid waste: a review on its benefits, potential and challenges to recovery landfills in growing cities in Indonesia

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Abstract. One of serious impacts of increasing human population in cities is the availability of land, strategic land in particular becomes rare and as a result, its value increases rapidly. Another impact is the amount of solid waste produced which also continues to increase sharply. Although the perception and knowledge of the community regarding solid waste is improving, it does not necessarily change their paradigm, mindsets and behaviors in minimizing solid waste, the landfill is still the final solution to solid waste. In general, the carrying capacity and supporting capacity of landfills in the cities have reached the maximum limit and must be closed immediately. Initially the locations of the landfills were far from city centres, but now generally they are in densely populated urban areas. Procurement of new landfill is constrained by regulations, costs, technical and social issues. NIMBY syndrome (not in my back yard) is the culmination of public rejection, and has even become a vertical conflict between the community and the government. The study of landfill mining, particularly the study of benefits, potential and challenges in choosing landfill mining, which is dominated by organic solid waste, is an interesting study to explore. The use of compost landfill mining as an organic fertilizer for plants, or as biocover is a logical argument for recover or extend the service life of old landfill.

1. Introduction
Rapid population growth has a serious impact on the amount of solid waste produced, especially in cities. The increasing amount of solid waste becomes more serious due to the changes in society’s lifestyles and consumption patterns as a result of an increase in urban income. Although the perceptions and knowledge of the urban community about solid waste are increasingly positive, it does not necessarily change their paradigm, mindsets and behaviours in reducing solid waste, and the landfill is still the final solution to solid waste [1–3].
The general characteristics of solid waste in developed countries are inorganic and dry solid waste, such as metal-containing waste - e.g. spring beds, chairs, car seats, etc - which can go through the combustion process easily. Thus, landfill mining in developed countries generally focuses on metal mining from incinerator ash deposits.

Meanwhile, in developing countries such as Indonesia, urban household solid waste is dominated by organic solid waste - which is up to 70% of the total solid waste entering landfills - and categorized as wet solid waste with a water content up to 80% [1]. This makes solid waste management with the combustion process impossible. However, the organic materials can decompose naturally and produce methane, carbon and water.

The main objective of this paper is to examine the unique landfill mining concept which is different from the concept of landfill mining in developed countries, i.e. the landfill mining which is dominated by organic solid waste, so that the results obtained are also unique and different, such as decomposed organic material mass in the form of fine soil-like material, called compost landfill mining.

2. Definition of Landfill Mining
From the economic aspect, it is stated that the cost of solid waste management with the spreading system in landfills is lower than solid waste management with incinerators [4]. However, population density factors need to be considered - in areas with low population and land availability, a landfill is still a better choice [5]. Whereas in densely populated areas in which land prices continue to increase rapidly, obtaining sites for new landfills that comply with regulations will be difficult and generally fail [6,7].

From an environmental perspective, disposal of solid waste into landfills, both by burying and leaving them without management, is a serious mistake, because the solid waste still contains energy and materials which can be utilized [8,9]. One way to get back the materials is by digging up the waste. The activity is known as Landfill Mining (LFM), which is a process for extracting other solid materials or natural resources from solid waste materials that has previously been disposed of by burying it in soil [10].

Landfill Mining is a way to recover resources buried in landfills and minimize environmental burdens caused by emissions from landfills [11]. Landfill mining can extend landfill service life; repair and recover land conditions; and restore the adverse environmental effects of leachate pollution and gas emissions produced by landfill [10,12,13]. Another definition of landfill mining is a process of extracting solid waste from old landfills with the aim of treating the unprocessed solid waste in order to be used as a resource, for example as secondary raw material or as a raw material for substitute fuels "Refused Derived Fuel" [14].

3. Benefits of Landfill Mining
Limitations of urban land require good management of the landfill, so that the service life of the landfills can be extended. Landfill mining is one of alternatives to achieve the goal. The process includes extracting, sorting and reusing materials which are still useful from landfills. Thus, landfill mining has the potential to recover and reuse landfills.

Furthermore, landfill mining can also reduce and restore the adverse effects of the environment that can threaten the health of local communities. These adverse effects include ground water pollution by leachate into the soil. Meanwhile, air pollution can occur from carbon gas and methane gas emissions [12].

In addition to its economic benefits and environmental recovery, other indirect benefits of landfill mining activities include being able to avoid obstacles (e.g. legal, environmental impact, community acceptance) and large costs through low costs of land liability and cover [15]. Therefore, landfill mining can be adopted as a viable way of ecological recovery of landfills [16,17].

Some literature states that the benefits, costs and environmental impacts of landfill mining activities depend much on several factors, such as age of land, characteristics of excavated materials, landfill depth, waste decomposition level of decomposition, content of hazardous materials, waste management methods, economic/social developments of local communities, climate, humidity and landfill location.
Therefore, in order to find out the full potential of a landfill, it is important to conduct both qualitative and quantitative analysis of the characteristics of the excavation materials beforehand.

Other indirect benefits that can also be obtained from the selection of land mining are the restoration of the aesthetic values in the region, including recovery from the impression of being dirty, slum, bad smell, dust, flies, rats and stray dogs. The recovery of aesthetic values has a real impact on the landfill recovery and increases the economic values of the landfill and its surrounding areas. This is because the existence of landfill has a negative impact on the price of nearby houses and buildings.

The impact of the decline in environmental quality also has a close relationship with the social conditions of the community. Therefore, the presence of landfills is often a cause of social conflict with the surrounding community. This social conflict has become a common phenomenon in big cities in Indonesia, and has even led to a vertical conflict between the community and the local government. Strong protests from the community have given birth to NIMBY syndrome (not in my back yard).

Both of newspaper and television media have often reported public protests about the existence of landfills, including:

i. In 2003; Community protests to the Surabaya government against the closure of the Sukolilo landfill, because in the 2000 protest it was agreed that the deadline for closing the landfill would have been in 2002.

ii. In 2009 and 2016; Community protests against Galuga landfill in Bogor, West Java.

iii. In 2010; due to the trauma of the 2005 landfill landslide tragedy which claimed 157 deaths and removed 2 villages from the map, the community around Leuwi Gajah landfill in West Java rejected the plan to reactivate the site.

iv. In 2017; Public protest against the end of the operation period of the Pasir Bajing landfill in Garut, West Java.

v. In 2018; Conflict between the government of Bekasi city and the DKI Jakarta government regarding compensation payment for the community around the Bantar Gebang landfill in Bekasi, West Java, for its decreasing environmental quality.

4. Landfill Mining Potential

4.1. Raw Materials Recycle

The composition of solid waste in Indonesia generally consists of 70% of organic solid waste, and the rest is inorganic solid waste. These inorganic solid waste have the potential to be reused or recycled into new products or other products. This is because most of the inorganic solid wastes still have economic value or calorific value as an energy source. Some of them are paper waste, plastic, glass, metal and batteries.

Most of formal sectors in Indonesia have not been able to carry out the process of sorting solid waste, so the activity is generally carried out by the informal sector, namely scavengers. Scavengers are people who treat rubbish as something of value, a source from which high-value materials can be obtained.

In general, landfills in Indonesia have not been properly managed, so they are categorized as being dirty and smelly, and a source of diseases. Scavengers and people who live around the landfills are highly susceptible to diseases and exposure to toxic and hazardous gas emissions. Therefore, there must be a paradigm shift from collecting used goods manually by scavengers to the paradigm of using a environmental quality and high market demand for recycled raw materials.

4.2. A Source of Organic Fertilizer

Organic solid waste is rubbish whose constituent materials come from living things produced by nature or by human activities. Household solid waste is one example of many sources of solid wastes produced by human activities. The examples of organic household solid waste includes food scraps, vegetables, fruits, leaves, meat, vegetable/fruit peel, etc. The long term impact of the accumulation of organic solid waste is the decomposition of these organic solid wastes into fine materials resembling soil, called compost.
Composting is a fermentation process or also known as the process of organic material degradation caused by oxidation. The decomposition will produce carbon dioxide and water, so that the remaining biomass becomes a component that is simpler, stable and resembles humus. The basic principle of composting is to reduce the comparative value of carbon and nitrogen (C/N) elements from organic solid waste to near to the value of the C/N ratio of land, which is less than 15 [33].

One of the physical characteristics of good compost is one that has a texture and smell like soil. Good compost can improve texture and maintain soil moisture. Good compost can also increase the content of organic matter and soil nutrients. Therefore, good compost can be used as fertilizer for agriculture, landscaping, nurseries, garden soil conditioning, golf courses and reforestation of critical lands. So, the market potential for demand for compost is very large. This condition provides a large space for landfill mining activities. In addition to its economic potential and recovery of environmental quality, landfill mining activities can also create jobs [34].

4.3. As Biocover

Soil-like fine materials obtained from the landfill excavation process which contain heavy metals or other hazardous toxic materials cannot be used as organic fertilizer for plants in the food chain. Instead, they can be used for other plants that are not for consumption. The soil can also be used as a landfill top cover (biocover). Thus, landfill mining not only can recover the lands of old closed landfills, but also can increase the service life of actively operating landfills [10,12].

To reduce methane gas emissions into the air, the landfill area can be covered by using soil and compacted until the thickness of soil of 20-30 cm. Reusing compost landfill mining as landfill top covers (biocover) not only reduces methane emissions from landfills, but also enhances the methane decomposition process to become carbon dioxide, water and biomass. This is because compost landfill mining contains various groups of microorganisms, especially methanotropic bacteria which can oxidize methane biologically, so that the use of compost landfill mining as biocover is better than using ordinary soil [35,36].

5. The Challenges on Selecting Landfill Mining

5.1. Highly Costs

In general, the cost of landfill mining is greater than income, so that landfill mining activities are not feasible without additional government mandates and funds [37,38]. However, for the municipal governments, landfill mining is important in order to obtain additional lands in densely populated areas. Therefore, the issue of additional funding needs is not a serious consideration. This is due to the value of the recovered lands which exceeds the value of the landfill contents [15,39].

5.2. Heavy Metal Content and Hazardous Toxic Material

In the past, landfill management used an open dumping system without facilities to control environmental quality. The most serious impact of this practice is ground water contamination by leachate. Any landfill will produce leachate, that is liquid produced by dissolving organic and inorganic compounds as the result of physical, chemical and biological processes of solid waste decomposition; The source of the liquid can come from the solid waste itself and rainwater in landfills.

Shallow groundwater is found in the depth up to 20-40 meters underground, for example wells or shallow bore wells which are used as clean water sources by people who do not have access to water from the PDAM (water company). If the water source is polluted, the water quality will decrease and have a serious health impact on the community.

Jaya [40] have reported that up to a distance of 400 meters from landfills, the quality of community water wells is categorized as heavily polluted. From the report presented in Table 1, it can be seen that the heavy metal contents of cadmium (Cd) and lead (Pb) up to a distance of 100 meters away from the landfill are 0.019 mg/l and 0.981 mg/l, respectively. These results are higher than the specified quality standard: 0.01 mg/l for cadmium (Cd) and 0.03 mg/l for lead (Pb). At a distance of 400 meters away
from the landfill, although cadmium content has dropped to 0.003 mg/l (below the quality standard), lead content reduces to only 0.602 mg/l (still above the quality standard).

**Table 1.** The results of measuring the quality of wells around Suwung landfill in Bali

| Parameters   | Units | Class I Water Quality Standard (Bali Governor’s Regulations No. 8/2007) | Results (Based on distance of samples from the landfill site) |
|--------------|-------|-------------------------------------------------------------------|-----------------------------------------------------------------|
| Cadmium (Cd) | mg/l  | 0.01                                                              | 0.019 0.003                                                      |
| Lead (Pb)    | mg/l  | 0.03                                                              | 0.981 0.602                                                      |

The content of heavy metals is also found at 4 landfills in West Java as presented in Table 2 [41]. These heavy metals include copper (Cu), chromium (Cr), zinc (Zn), lead (Pb) and cadmium (Cd). Heavy metal content is also found in the Sukolilo landfill in Surabaya. The content are 0.087 mg/l for Cd, 0.593 mg/l for Pb and 1.067 mg/l for Cr, respectively [42].

**Table 2.** Contents of some heavy metals at 4 waste landfills in West Java

| Parameters | Jelekong Landfill | Pasir Impun Landfill | Leuwi Gajah Landfill | Sarimukti Landfill |
|------------|-------------------|----------------------|----------------------|--------------------|
| Cu (ppm)   | 7.00725           | 12,1166              | 12,3735              | 12,2879            |
| Cr (ppm)   | 1.65529           | 3,128                | 3,7935               | 4,5102             |
| Zn (ppm)   | 9.74202           | 4,4761               | 4,2712               | 4,6744             |
| Pb (ppm)   | 4,76249           | 14,1736              | 15,2153              | 14,9236            |
| Cd (ppm)   | 0                 | 0.2755               | 0.4057               | 0.3201             |

**Figure 1.** Construction of playground/city recreation park on the closed Sukolilo landfill in Surabaya. (Source: Observation results on October 1, 2017)
Figure 2. Construction of residential homes on the closed Sukolilo landfill in Surabaya. (Source: Observation results on October 1, 2017)

Based on reports of the contents of heavy metals and other hazardous toxic substances potentially found in landfills in developing cities in Indonesia, the utilization of the former landfills as city forests is a wise decision made by municipal governments. This is considering that soil and groundwater contamination by leachate can last for a long time and can reach 30-50 years [43].

However, the use of closed landfills as city playgrounds, recreational park or even for residential developments is a questionable decision (Figure 1 and Figure 2). As the health and safety aspects of the land users are still in doubt, the study of all aspects (which will take a long time and require large funds) must be done first. This is based on the consideration that the landfill management in the past has not specifically separated the solid waste: domestic, medical and industrial waste.

5.3. Researched on Potential of Landfill Mining
Landfilled wastes buried for a long time can be excavated and used as compost for plants or can also be reused as biocover for actively operating landfills. The excavation of the landfill is termed landfill mining. The series of landfill mining activities include excavation, drying, sorting organic and inorganic waste, enumeration, screening and weighing to determine the composition of the extracted materials.

Studies to examine the potential of landfill mining in Indonesia have been carried out by several researchers. For example, a research at Sukolilo landfill in Surabaya found that the composition of the landfill materials is as follows: soil 34.26%, plastic 38.10% and others 2-10% as wood, cloth, rubber and metal [44].

Another research was conducted at the Ngipik landfill in Gresik district. Based on the mass balance of excavated materials, it was reported that 97.57% of the materials obtained could be reused and the remaining 2.43% in the form of rubber, glass and others were materials that could not be utilized. Some of the materials that can still be reused include 25.91% compost, 19.37% urug material and the rest are plastic, wood and fabric, which can be used as raw materials for refused derived fuel (RDF) after requiring further processing. Detailed data from the excavation results are presented in Table 3 [45].
5.4. Waste Management Problem in Indonesia
In Indonesian law (UU No. 18, 2008) of Solid Waste Management states that it local governments are obliged to close every landfill which uses an open dumping system no later than 5 years after the law came into force. It means that by 2014 there is no open dumping landfill in Indonesia. Nevertheless, in reality, the local governments are not able to obey the law [46].

Lack of accurate data on solid waste, lack of facilities in landfill sites, lack of efforts to compost and recycle waste are evidence that the technical aspects, costs and human resources are serious obstacles in local solid waste management. This fact is in line with the Executive Summary data of the 2013 Sanitary Landfill Policy Study of the Coordinating Ministry for Economic Affairs of the Republic of Indonesia who stated that the technical, financing and quality aspects of human resources are the main obstacles in implementing a landfill using a sanitary landfill system [47].

Solid waste problems, especially in developing cities, are increasingly complicated by the high rate of urbanization, which directly affects the population and the amount of solid waste produced. Although the perceptions and knowledge of the urban community about solid waste are increasingly positive, it does not necessarily change their paradigm, mindsets and behaviors in minimising solid waste significantly; landfills are still final solution for solid waste, which in turn present serious problem for local governments [1–3].

5.5. Regulations
Article 28H paragraph 1 of the UUD 1945 states that everyone has a right to good and healthy environment. Furthermore, Article 33 paragraph 3 states that the earth, water and natural resources contained therein are controlled by the state and used as much as possible for the prosperity of the people [48]. The prosperity is not only for the present generation, but also for future generations. To guarantee sustainable prosperity, the Government and the House of Representatives agreed to issue Republic of Indonesia Law Number 32 of 2009 concerning Environmental Protection and Management. The mandate is clearly stated in article 1 paragraph 3: sustainable development is a conscious and planned effort which combines environmental, social and economic aspects into development strategies in order to ensure the environmental integrity as well as the safety, capability, welfare, and quality of life of present and future generations [49].

These three aspects are also applied in solid waste management. This means that solid waste management activities must ensure the integrity of the environment and carrying capacity of the environment. Solid waste management must also profit and provide economic benefits for the community and the region. Therefore, solid waste management activities must also consider the socio-cultural aspects of the local community so that community involvement, participation and empowerment can be fully achieved.

Increasing population and changes in communities’ consumption patterns are among the main causes of the current increase in the amount of solid waste. In general, throughout the territory of the Republic of Indonesia, solid waste management is also not in accordance with the methods and techniques of

| Components  | Compositions (%) | Utilization     |
|-------------|------------------|-----------------|
| Fine Material | 25.91            | Compost         |
| Rough Material | 19.37            | Additional soil |
| Plastic      | 41.40            | Alternative fuel / RDF |
| Wood         | 5.31             | Alternative fuel / RDF |
| Linen        | 5.49             | Alternative fuel / RDF |
| Iron/metal   | 0.09             | Recycle         |
| Rubber       | 1.40             | Re-landfill     |
| Glass        | 1.01             | Re-landfill     |
environmentally-friendly solid waste management, thus having negative impacts on the health of the local community and the surrounding environment. Therefore, the Indonesia Government considers that solid waste problem is a national problem; its management needs to be carried out comprehensively and integratedly so that it can provide both economic and health benefits for the local community, and safety for the environment. In order for solid waste management to be carried out proportionally, effectively and efficiently, legal management, responsibility and authority are needed in solid waste management, either for the central government, regional governments, community or the business world. Based on these considerations, the Government and the House of Representatives of the Republic of Indonesia agreed to pass Law No. 18 of 2008 concerning Solid Waste Management.

Law No. 18 of 2008 [50] explains in details and in full: the definitions of terms of solid waste and solid waste management, the scope of solid waste management, principles and objectives of solid waste management, government duties and authorities (for central government, provincial governments and regional governments), as well as the rights and obligations of each individual regarding solid waste. Other important points in the Act include a special chapter on the implementation of solid waste management (household solid waste and household-like solid waste), solid waste reduction regulations, solid waste handling regulations, and specific waste management rules. Other important material contained in the Law includes the role of the community in solid waste management, prohibitions relating to the solid waste, supervision, administrative sanctions, criminal provisions and transitional provisions. There are some interesting points stated in the transitional provisions chapter, including the affirmation of each regional government to make a plan to close the open dumping system landfill no later than 1 (one) year after the enactment of Law Number 18 of 2008. The next assertion is that the regional government must close any landfills which uses an open dumping system within 5 (five) years from the enactment of Law Number 18 of 2008. The affirmation is also addressed to managers of residential, commercial, industrial, special, public, social and other facilities which do not have solid waste sorting facilities before the enactment of Law Number 18 of 2008 to build or provide solid waste sorting facilities within 1 (one) year.

To regulate more clearly the specific provisions of several articles in Law Number 18 Year 2008, the government stipulates Government Regulation Number 81 of 2012 concerning Management of Household Solid Waste and Household-like Solid Waste. The Government Regulation includes a regulation on solid waste management in question, with the aim of maintaining public health, preservation and functioning of the environment, and making the solid waste as a resource. The regulation on the solid waste management includes policies, strategies, implementation, guidance, information systems, community roles, compensation, and the development and application of technology [51].

There are some very interesting things from the direction of policy, strategy and implementation of solid waste management referred to in the Government Regulation, including the reduction and handling of solid waste. Solid waste reduction includes limiting solid waste generation, recycling and reusing. Meanwhile, solid waste handling includes sorting, collecting, transporting, processing and final processing of solid waste. The final solid waste processing referred to in the Government Regulation is directed to the district/city governments to use controlled landfill methods, or sanitary landfill methods, or environmentally-friendly technology.

The Government Regulation still requires further guidance so that it can be implemented by the regional governments. Law No. 18 of 2008 mandates the relevant ministers to prepare further instructions. For example, the Regulation of the Minister of Public Works of the Republic of Indonesia Number 03 of 2013 concerning the Implementation of Solid Waste Infrastructure and Facilities in Handling Household Solid Waste and Similar Household Solid Waste [52]; and the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 59 of 2016 concerning Standard Quality of Leachate for Businesses and/or Landfills [53].

To achieve the quality set by the government, the National Standardization Agency stipulates the Indonesian National Standard (SNI) for every activity and goods produced and marketed within the territory of the Unitary State of the Republic of Indonesia. Some of the standards relating to solid waste
include SNI 19-3964-1994 concerning Methods of Collecting and Measuring Samples of Solid Waste Generation and Composition of Urban Solid Waste [54]; SNI 19-2454-2002 concerning Procedures for Operational Management of Urban Solid Waste [55]; and SNI 3242:2008 concerning Solid Waste Management in Residential Settlements [56].

The above explanation illustrates that regulations regarding solid waste management in Indonesia are adequate for a developing country. However, changes in behaviours, perceptions and paradigms about solid waste and its management expected from the community, economic players and the government still require time. The inability of most local governments to close open dumping landfills is an evidence that costs and human resources are still the main obstacles in solid waste management. Their inability to procure new lands for controlled landfills or sanitary landfills is a challenge and provides potential for landfill mining activities in order to increase landfill service life or recovery of open dumping landfills.

6. Conclusion
6.1. Conclusion
i. Naturally, any organic material can decompose to produce gas methane, carbon, water and soil-like fine material, called compost. Thus, the recovery of landfills dominated by organic solid waste can be done using landfill mining methods, from which compost rich in nutrients can be used as organic fertiliser for plants.
ii. To find out the potential in each landfill, the physical, chemical and biological characteristics of the excavated materials should be analysed beforehand.
iii. The analysis results of the chemical characteristics of the landfill mining compost will determine its proper use: organic fertilizer for plants or biocover for actively operating landfills.

6.2. Suggestion
i. In order to reduce negative impacts on the environment and also to avoid lawsuits from landfill mining activities, the environmental impact analysis (EIA) must be prepared first.
ii. Recovery of leachate ponds is not included in this review study. Therefore, before landfill mining activities are carried out, in-depth studies on the recovery of leachate ponds and studies on the environmental impact analysis (EIA) must also be carried out beforehand.

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