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Assessment of CO_2 Emission and Energy Reduction on Solid Waste in Jeram Landfill Using Warm Analysis

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Abstract: Today, the increasing of solid waste generation became the major issue in Malaysia due to high population growth. The greenhouse emission and high energy consumption resulted from improper management of solid waste have caused a significant effect on the inhabitants and the environment. Hence, it is necessary to develop an integrated solid waste management plan to combat this problem. The challenges are to educate the communities in managing their own waste in a good manner. Recycling awareness among society should also be emphasized to ensure that waste generated can be properly managed. This paper focused on the greenhouse gases (GHG) emissions and energy consumption of municipal solid waste management. The aim of this research is to estimate the income generated from recycling activities from the municipal authority in Shah Alam and Klang district in Selangor. The analysis was done using waste reduction model (WARM) created by the Environmental Protection Agency (EPA), United States. The results indicated that the GHG emission that can be reduced by the Klang authority was 3,024.20 metric tons of carbon dioxide equivalents ($MTCO_2E$) compared to 2,577.80 $MTCO_2E$ for Shah Alam authority. The same result has been obtained for the energy emission which indicated the highest saving was 824.90 metric tons of coal equivalents (MTCE) by the Klang authority. However, the Shah Alam authority can only save the amount of 702.80 MTCE. The total incremental of energy used generated by WARM showed that Klang authority can save 23,290.20 million British thermal unit (MBTU) compared to Shah Alam authority of 19,862.80 MBTU. The percentage difference between the Klang authority and the Shah Alam authority in the GHG and energy emission reduction was approximately 14.80%. The total income from recyclable materials for Klang and Shah Alam authority was obtained as RM 918, 638.16. The estimation of GHG emission from both Klang and Shah Alam authority was depending on the solid waste generated and disposal method. In terms of GHG emission, waste separation includes recycling activities could reduce the GHG emission, less air pollution and more environmentally friendly.

Keywords: GHG emissions, energy consumption, municipal solid waste, waste separation, WARM analysis

1. Introduction

Municipal solid waste management in Malaysia has been facing many challenges since a few decades ago. Rapid population growth and urbanization have generated a large amount of municipal solid waste (MSW) nowadays. The generation of municipal solid waste (MSW) has increased by 95 percent over the past 10 years due to the rapid development in the urban area [1]. Solid waste covers all domestic wastes and non-hazardous waste such as commercial and institutional discharge, waste from roads and waste from construction activities.

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The effective urban solid waste management can reduce the amount of waste that needs to be managed and in turn able to create an effective collection and disposal system [2]. Hence, urban solid waste should be systematically managed without jeopardizing the environment, land and water resources. Generally, the amount of solid waste produced by a community depends on the way of life and culture, socioeconomic status, season, population and national progress. The expansion growth of population was due to the high development of the country, which increases the yield of solid waste indirectly. This brings impact on the excessive management cost of municipal solid waste. Furthermore, numerous odor and pollution coming from the multiple sources of reception and handling of this unwanted material would create severe environmental and health issues.

The municipal solid waste (MSW) generated has significantly impacted the human life, health hazard and emitting the greenhouse gaseous (GHGs) [3]. Recent research studied on the world's largest emitter for GHGs in India's landfill has estimated 16 MT CO_2 equivalents per year. However, this figure will rise to 20 MT of CO_2 equivalents per year in 2020 [3].

Hence, recycling is the best choice to reduce the solid waste to the landfill and saving the environment. The waste materials can be changed into new products to prevent waste of using other materials. The consumption of fresh raw material can be minimized by applying recycling activities. In this way, the problem of high energy usage, air and water pollution created from conventional waste disposal and greenhouse gas emission can be resolved [4].

Integrated waste management by segregation would reduce the amount of MSW. This method would decrease the solid waste going to the landfill and lower the GHG emission to the surrounding environments [5]. Prolong to that, the GHGs, mostly the release of carbon dioxide (CO_2) is associated with global warming. Furthermore, incorporating reduce, reuse and recycle would eventually cut down the emission of CO_2 to the atmosphere [6].

Insight, the energy saving, and carbon reduction potential from the recycling waste have been done by Dong *et al.*, (2018) [7]. In the research study, the potential reduction of 6.6% of energy can be saved with the total of 4.9% of CO_2 emission in the Shanghai province, China [7]. This case study showed the importance of recycling activities as the segregation method can be implemented to reduce energy consumption and GHG emission.

The Malaysia Government has developed the 11th Malaysia Plan Selected Outcome by Solid Waste and Public Cleansing Management Corporation (SWCorp). This is to focus on adopting sustainable consumption and production [8]. This task was done by managing waste holistically through better coordination. Here, the approach was to encourage 3R (Reduce, Reuse and Recycle) and using waste as resources for the industries.

It has been foreseen that the law and regulations on solid waste separation and handling have been imposed (National Solid Waste Management Department). However, the solid waste segregation has not been fully implemented by the citizens so far. This is because the recycling awareness on solid waste handling among the society is still at a very low level [9].

Recent research showed that waste management systems need to have an adequate analysis tool. The systematic approach in providing the comprehensive representation has to be evaluated. This can be described best in a model of flow for the waste through several treatment options [10]. From this model, several factors can be taken into account to assimilate the analytical framework for the best management practice on the MSW [10].

Therefore, the main objective of this study is to quantify the greenhouse gases (GHG) emissions and energy reduction rate with the impact of recycling activities in Shah Alam and Klang district in Selangor. This estimation was based on the source separation of municipal solid waste using waste reduction model (WARM) from these two areas of study. The analysis from this model would eventually evaluate the GHG emission and energy saving. Thus, can reduce the quantity of waste to the landfill and combat global warming.

2. Material and Methods

The case study was carried out at Jeram Landfill, Selangor, Malaysia. The data was obtained from Worldwide Landfill Sdn. Bhd. for Selangor Local Authorities; Shah Alam Municipal Authority (MBSA) and Klang Municipal Authority (MPK).

2.1 Waste Reduction Model (WARM)

The data has been analyzed by the composition of municipal solid waste (MSW) using WARM Model. The waste generated was a study based on the landfill baseline compared to the landfill/recycle/composition/ton reduced in the WARM model to indicate the emission of GHG. The model calculated the emissions across a wide range of material types commonly found in municipal solid waste to the following outputs:

a) Metric tons of carbon dioxide equivalent ($MTCO_2E$)
b) Metric tons of carbon equivalent (MTCE)
c) Energy units (million British thermal unit-MBTU)

The WARM model simulated up to five post-consumer materials management options including recycling, composting, combustion, anaerobic digestion, and landfilling depending on the material given. This model also would identify source reduction as an alternative materials management option [11].

Mohareb et al. [12] have stated by examining the differences in emissions from the quantification tools and guidelines in the WARM model would easily visualize the shortcomings and the methodological differences to the view of the professionals. Furthermore, the evaluation of this model with regard to the various treatment options and the selection of several methods stated in the WARM model would also help the other researchers on the assessment of waste management [12].

2.2 WARM in This Study

This paper focused more on the recovery of the recycling method. Here, when a material has been recycled, the WARM model would assume that the recycled material has replaced the use of virgin inputs in the manufacturing process. This assumption is based on the demand for new materials or products. Hence, providing the demand for recycled materials remained constant. In other words, increased recycling does not cause more (or less) material to be manufactured or being produced [13].

2.3 GHGs and Energy Savings in WARM

GHG savings are calculated by comparing the emissions associated with the alternative scenario. In this case, the emissions associated with the baseline scenario could not be interpreted as multiplying the quantity by an emission factor [11]. Here, two scenarios are necessary for applying WARM energy factors. There is a baseline scenario that represents current management practices and an alternative scenario that represents the alternative management practice. Following these scenarios, it is possible to calculate the amount of energy consumption or avoided in the baseline and alternative management practices. From that, the difference between the alternative scenario and the baseline scenario would be calculated. This result represented the energy consumed or avoided which attributed to the alternative management scenario [11].

2.4 Income Generated from Recyclable Materials

The income generated from recyclable materials was calculated from the weight after recovery. This was obtained from the total weight of MSW within seven days using MSW Fact and Figure 2012 ratio [14] (Fig. 1). The weight from each material was obtained by multiply the separation percentage ratio with the total recovery weight. This estimation was based on MSW Fact and Figure Recovery [14] (Fig. 2) and Klang Valley household composition ratio (Fig. 3). The revenue from recyclable materials was calculated by multiplying each composition with market price stated by JPSPN (2013) [15] (Table 1).

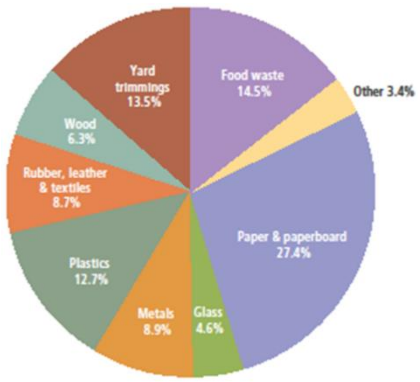

Fig. 1 - Total MSW generation 251 million tons (before recycling-by material) [14]

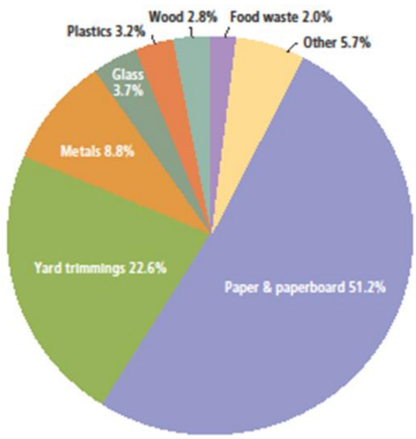

Fig. 2 - Total MSW recovery (87 million tons-by material) [14]

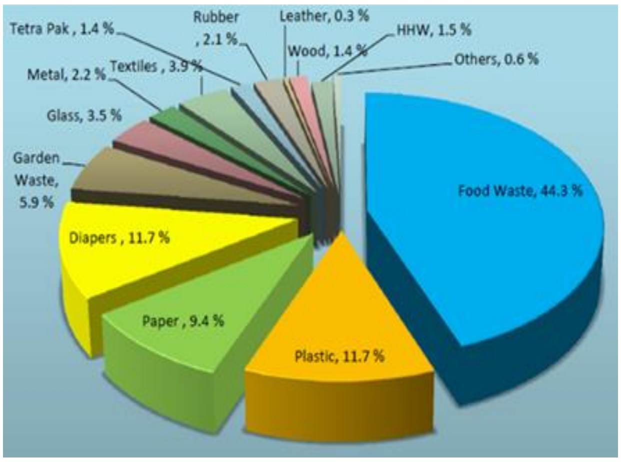

Fig. 3 - Klang Valley household waste composition (as generated) [15]

Table 1 - Market price of recyclable generated [15]

Composition	Market Price (RM/kg)
0.1	1340
0.3	1230
0.5	1215
0.8	1200

Fig. 4 shows the flowchart of the frameworks on the analysis method of this research study. These illustrate the steps for the MSW data being obtained from the Jeram Landfill. This data was then calculated for the weight and the total amount based on Fig. 1 and Fig. 2. The obtained results were then evaluated using the WARM analysis in calculating the GHG emission and the energy saving in carbon dioxide equivalents (MTCO$_2$E) and metric tons of coal equivalents (MTCE).

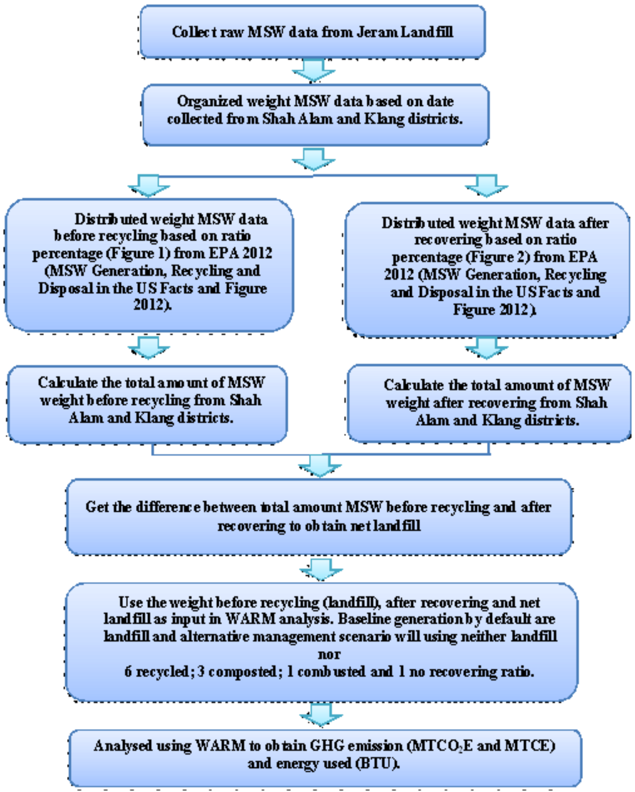

Fig. 4 - Flow chart of the frameworks on the analysis method

3. Results and Discussion

Fig. 5 shows the total incremental of GHG in the form of carbon dioxide (CO_2) equivalents ($MTCO_2E$) for both MBSA and MPK. It displayed the source-segregated materials recycling developed in this research study. From Fig. 5, it can be noted that a net value which is positive value represents $MTCO_2E$ saving emissions. Nine materials were indicated as the result of net $MTCO_2E$ savings from the recycled materials analysis. The two non-recycle materials, which were yard trimmings and mixed municipal solid were for composting method have shown negative values for incremental GHG emissions.

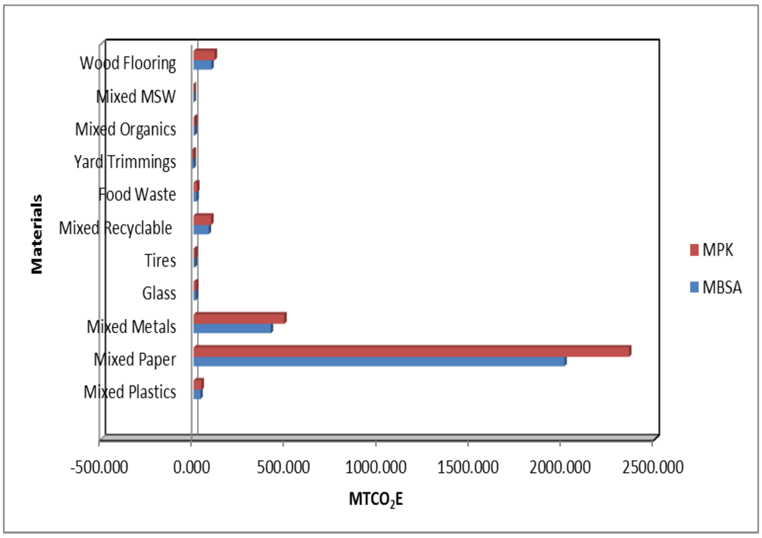

Fig. 5 - Total incremental $MTCO_2E$ emission

The extent of these savings varied considerably between different materials for MPK. The highest savings of total incremental GHG emission for $MTCO_2E$ was found to be mix paper with 2,359.50 MT compared to MBSA which stated only 2,009.30 MT. The material of yard trimming indicated the highest incremental of GHG emission which was recorded by MPK with 9.70 MT compared to 6.10 MT (MBSA), respectively.

The result of carbon emission for the ton produced is based on Fig. 6. This result shows the highest GHG emissions saving of MTCE from mixed paper for MPK as 643.50 MT. The materials of yard trimmings for MPK has been considered as the highest incremental of GHG emission (2.60 MT) compared to MBSA (1.70 MT). It can be explained that the subsequent situations such as source reduction and recycling could influence the net of GHG emissions of the material produced.

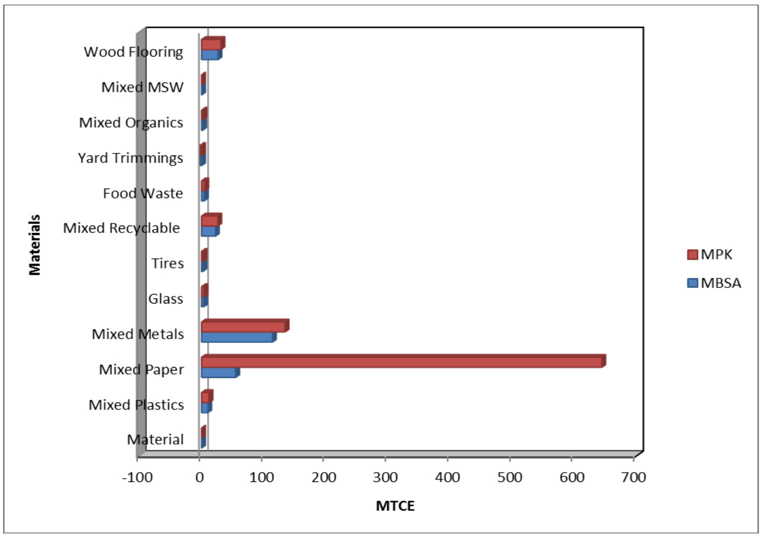

Fig. 6 - Total incremental MTCE emission

The energy use from baseline and alternative management system was determined using the WARM model. The result from MPK showed the highest incremental of energy saving consumption. This material was from mixed paper with the value of 13,296.80 MBTU. However, the maximum value of energy consumption recorded by MPK was on yard trimmings material (129.60 MBTU) shown in Fig. 7.

In comparison with Mohareb et al. (2011) [12] which similar research using WARM has found that carbon sink of 53 kt of CO_2 equivalents. This has outlined that WARM model is in principle of calculating the carbon credits by sequestration of organic carbon. Whereby, when the aerobic conditions all carbons are broken down completely and the carbon dioxide gaseous (CO_2) is released to the atmosphere. After that, these gaseous of (CO_2) are captured in the photosynthesis process via plants [12].

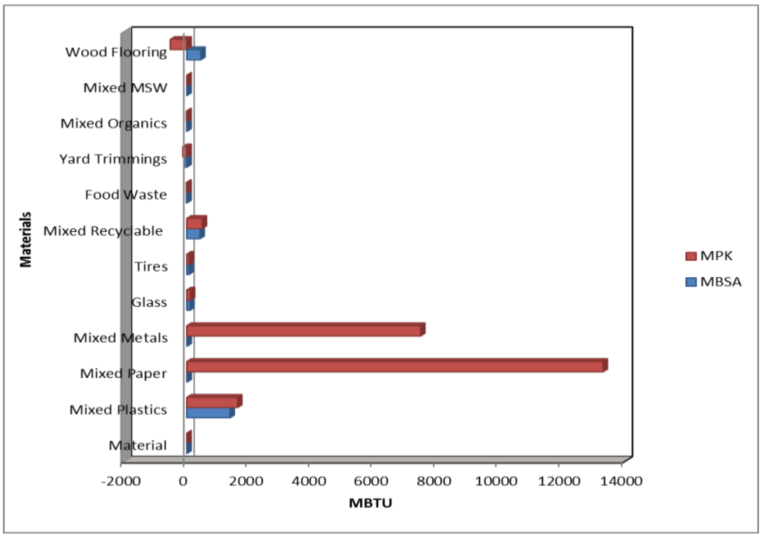

Fig. 7 - Total incremental energy consumption

Fig. 8 shows the total incremental GHG emission of $MTCO_2E$ both for MBSA and MPK for seven days period (1 week). The graph indicates the total saving incremental of core recyclable material for MPK is the highest value (3,011.50 MT) with 910.90 tons of total recyclable solid waste generated. The total incremental saving of GHG for other material obtained from MBSA was 315.43 tons $MTCO_2E$. Hence, the value for MPK was 3,024.20 MT compared to 2,577.80 MT attained by MBSA.

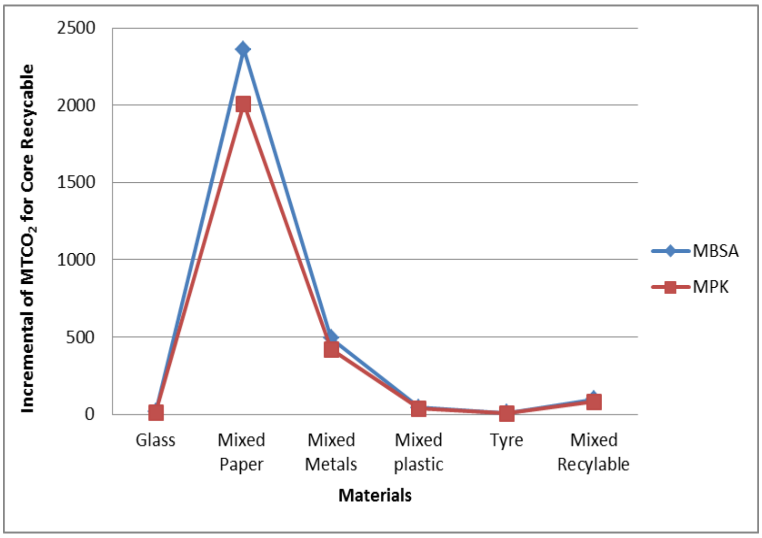

Fig. 8 - Total incremental of $MTCO_2E$ for core recyclable

The same result on the total incremental of core recyclable material for MTCE emission (Fig. 9) which gained the maximum saving. This has been recorded by MPK (821.40 MT) with 910.90 tons of recycled solid waste generated. MPK obtained the greatest total saving of energy used for core recyclable materials at 23,065.50 MBTU for 910.90 ton of waste generated (Fig. 10). Other materials also showed similar results, where MPK has recorded energy saving up to 224.70 MBTU for the weight of 370.40 tons generated. From that, it can be deduced that the maximum energy saving was from MPK (23,290.20 MBTU) for 1,281.30 ton of total weight generated compared to MBSA (19,862.80 MBTU-1091.14 ton).

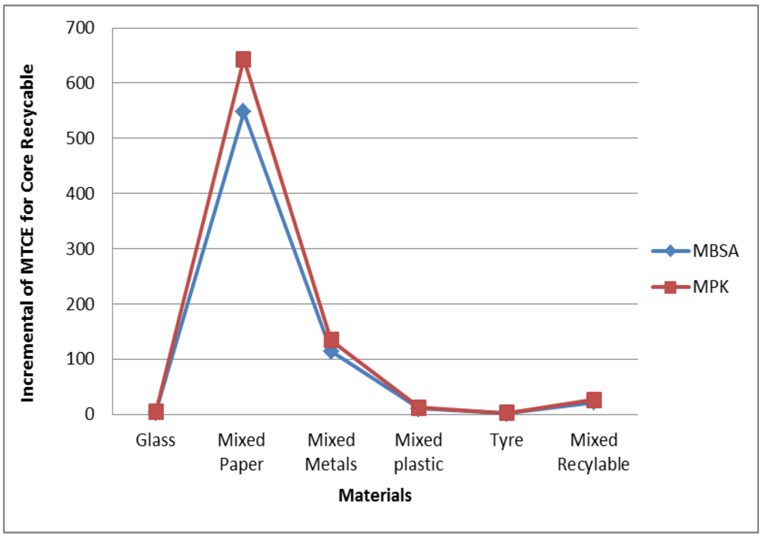

Fig. 9 - Total incremental of MTCE for core recyclable

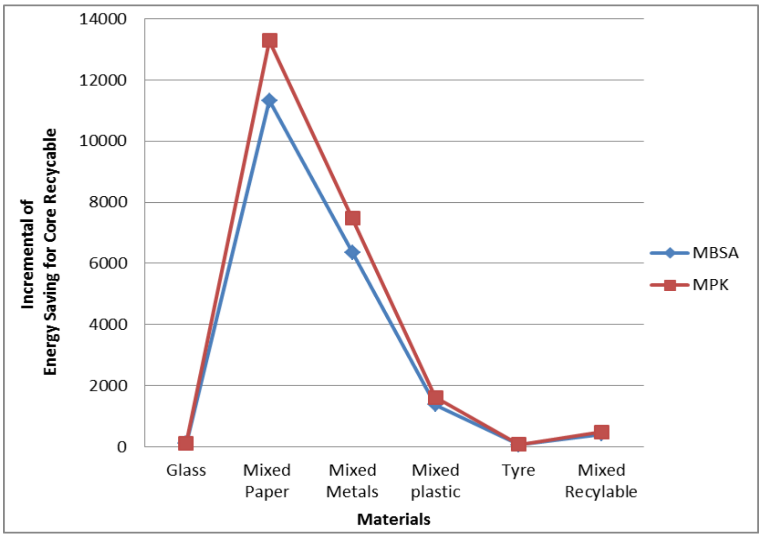

Fig. 10- Total incremental of energy used for core recyclable

The significant value for mixed paper in energy saving consumption was higher than GHG emission because of the differences in value factor; by which the energy factor was 20.45. Meanwhile, the emission factor was 3.53.

The results show the highest reductions of GHG emissions can be achieved through better sorting of MSW and recycling of waste. The highest savings from this waste stream were from mixed paper and mixed metal. This is from core recyclable items for MBSA and MPK with total incremental 2,564.70 MT and 3,011.50 MT, respectively. Based on the study, food waste from households, food manufacturing industry, and other sectors was responsible for the emissions of 15.80 and 18.50 of CO_2 equivalents in MBSA and MPK, correspondingly.

Fig. 11 and Fig. 12 show the estimation of revenue from recyclable materials for MBSA and MPK. The results show that by recycling the mixed recyclable (textiles) generated at the facility, the values of RM 141, 704.25 and RM 166, 402.15 can be obtained by MBSA and MPK based on JPSPN ratio [15]. Furthermore, high revenue can be gained from the mixed recyclable on textiles which can contribute to the highest income. This can be adapted by the local communities in the study area. Where they can practice the recycling activities for this recyclable and sell it back to the market.

It can be noted that paper was the biggest contributors to the recyclable item following to the EPA ratio [16]. This is based on the recyclable item generated which was RM167, 636.53 for MBSA. MPK had obtained RM 166,402.15 from mix recyclable materials.

A net profit of 19% more revenue can be generated using EPA ratio [16] compare to JPSPN ratio [15]. This can be found in Fig. 13, which shows the comparison of total income generated from recycling materials using EPA and JPSPN ratio. From this Fig. 13, the total income that can be generated using EPA ratio is RM 918,638.25 and RM 739,721.07 (JPSPN ratio), respectively.

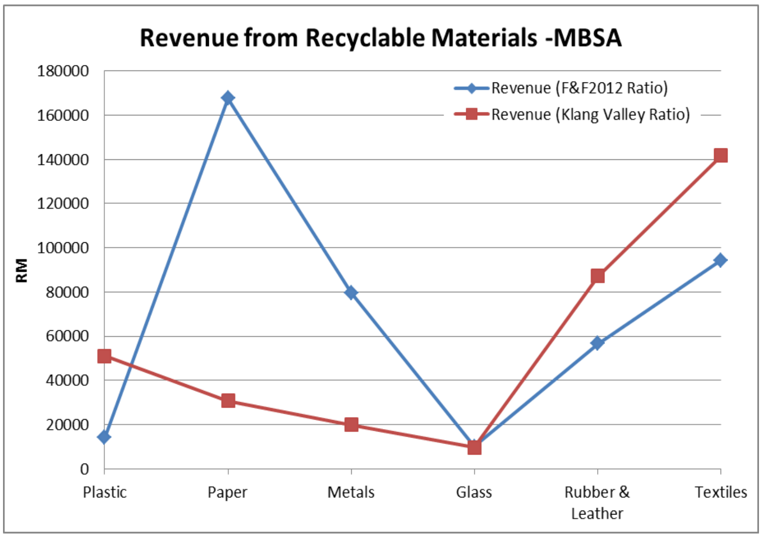

Fig. 11 - Estimation of Revenue from Recyclable for MBSA

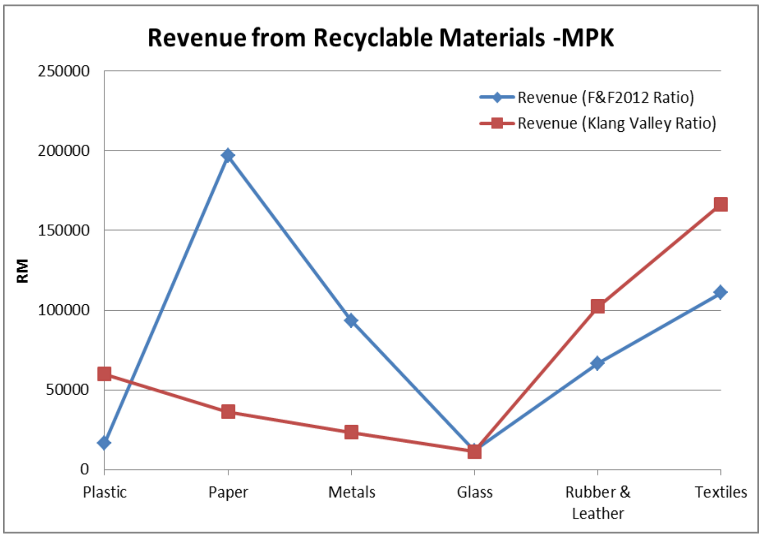

Fig. 12- Estimation of Revenue from Recyclable for MPK

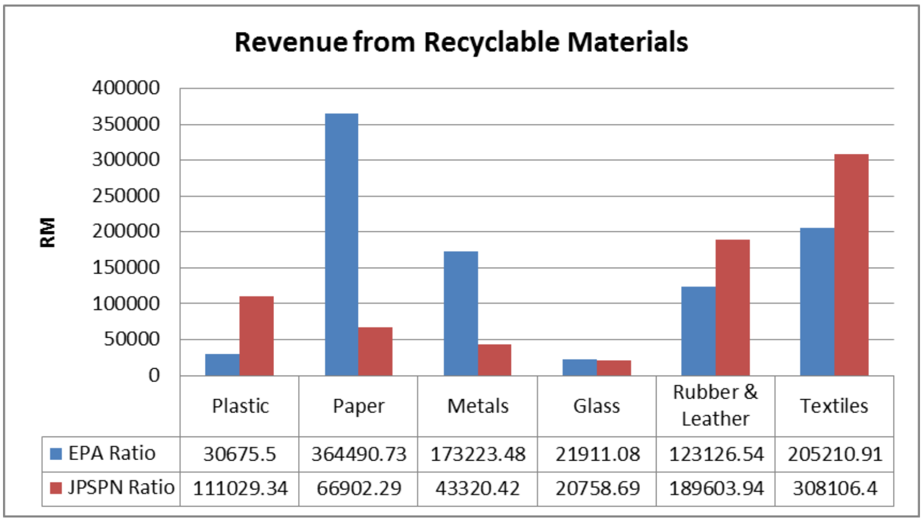

Fig. 13 - Comparison of Estimation Total Revenue from Recycling

This shows that the revenue for recycling using EPA ratio was higher than JPSPN ratio. The different amounts of money collected were based on the changed of lifestyle and social culture, by which the EPA ratio was established from the United States and the JPSPN ratio was from Malaysia.

Several research studies have shown that in assessing the CO_2 emission reduction would save the energy and reduce the cost effectively [17, 18]. In that research study, the analysis on cost reduction of CO_2 emission has been done until the year 2050 in China's oil and gas extraction industry [17, 18].

Sustainable approach on the carbon reduction of waste resources is a key factor and an effective way to cut GHG emission. Inter-firm collaboration on industrial symbiosis together with the participation of other citizens in one community is essential [18]. Prolong to that, significant reduction of solid waste produced can be targeted. The green integration of waste reduction techniques in the community and industrial players are vital [19].

This social and environmental responsibility of those involved would optimize the best practice to lower down the accumulation of solid waste. Basically, the emission of GHG is depended on the waste generated by the communities. The higher amount of waste produced would accumulate more GHG emissions. Hence, it is very crucial to reduce the GHG emissions in the environment.

This will minimize the impact on the environment as the pollutants can be diminished and control. For that, the safety and health of the local population can be preserved.

4. Conclusions

It can be concluded that by using waste reduction model (WARM), the GHG emission in term of CO_2 equivalents and energy saving can be evaluated and analyzed. From the data provided, it is ideal to quantify the waste using modeling approaches. In instances, the modeling tools can provide an estimation of emission for incoming years ahead. The estimation of emission reduction is an important tool to combat global climate change.

This is very important as most of the landfill in Malaysia had reached their maximum lifespans. In addition, acquiring a new site has become a very difficult task owing to land scarcity and high cost which was brought about by the country's economic growth.

The importance of recycling activities needs to be considered as the method to lessen GHG emissions and save energy consumption. Prolong to that, the waste separation and recycling would be the better option to overcome the problems. These options, if fully utilized would greatly minimize the number of wastes being disposed of in landfills and reduce the environmental impacts. The recycling activities can also generate income to the country and indirectly helps the country's economic growth.

Acknowledgement

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