OPTIMIZATION OF MUNICIPAL SOLID WASTE MANAGEMENT STRATEGY IN ISKANDAR MALAYSIA USING GENERAL ALGEBRAIC MODELLING SYSTEMS

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ABSTRACT

Municipal solid wastes (MSW) are the materials generated, collected and discarded of in municipal areas because of their no or less value to the generator. Thousands of tonnes of MSW are produced annually in Iskandar Malaysia (IM), and the rate continues to increase due to high population growth, high degrees of urbanization, and industrialization. This increase in the amount of MSW makes its effective management an issue of great concern because of the cost implications and the threat it poses to human health and the environment. Hence it is absolutely essential to search for a better strategy to manage it in an economically viable and environmentally friendly manner. Three mathematical optimization models using linear programmes were developed and implemented using relevant data of IM region. In view of that, this research developed and solved three mathematical models using general algebraic modelling system software as a tool. The research objectives are; (i) To develop a cost-effective strategy for MSW collection and transportation from points of generation to disposal/recovery for a typical IM region using linear programming minimizing cost. (ii) To develop a single period MSW utilization strategy for revenue generation from the recyclable components of MSW in IM using an optimization tool to maximize profit. (iii) To estimate the biogas to electricity generation potential of the organic components of the MSW in IM. The results show the optimal transportation cost of MYR 5.97 million per week. The MSW amount transported from municipals to landfills to achieve cost-effective outcome are Pasir Gudang to Tanjung Langsat (2452 metric tonnes), Kulai to Pekan Nenas and Seelong (512 and 1501 metric tonnes), Pontian to Pekan Nenas and Seelong (1739 and 2214 metric tonnes), Johor Bahru to Pekan Nenas, Seelong and Tanjung Langsat (1739, 7485 and 18 metric tonnes), Johor Bahru to Pekan Nenas, Seelong and Tanjung Langsat (1739, 6881 and 110 metric tonnes). The total trucks to each landfills sites are Seelong, 988, Pekan Nenas, 313 and Tanjung Langsat 141. The highest and lowest trips are from Johor Bahru to Seelong and Tanjung Langsat at 429 and 1 respectively. The results also show the minimized cost of sorting MSW into recyclable is MYR 572,000. The highest and lowest recycled components are organics and glass (46 and 19 metric tonnes) at sorting units 1 and 5 respectively. The minimized cost of electricity generated from MSW is MYR 143,000 per week. The decentralized model shows that the highest utilization of organic is at Kulai municipal (400 metric tonnes) and lowest at Pontian (50 metric tonnes). A cost saving from 2,157,777.40 before to 1,965,161.82 after minimization, which is 8.9% in reduction was achieved. The models are also viable for recycling and biogas generation.

ABSTRAK

Sisa pepejal perbandaran (MSW) adalah bahan yang dihasilkan, dikumpulkan dan dibuang di kawasan perbandaran kerana tiada atau kurang bernilai kepada penjana. Beribu-ribu tan MSW dihasilkan setiap tahun di Iskandar Malaysia (IM), dan kadarnya terus meningkat disebabkan oleh pertumbuhan penduduk, tahap perbandaran dan perindustrian yang tinggi. Peningkatan jumlah MSW ini menjadikan pengurusan yang berkesan sebagai isu yang sangat membimbangkan kerana implikasi kos dan ancaman yang timbul ke atas kesihatan manusia dan alam sekitar. Oleh itu, adalah penting untuk mencari strategi yang lebih baik untuk mengurusnya secara ekonomi dan mesra alam. Tiga model pengoptimuman matematik yang menggunakan program linear telah dibangunkan dan dilaksanakan menggunakan data berkaitan kawasan IM. Oleh itu, penyelidikan ini telah membangunkan dan menyelesaikan tiga model matematik menggunakan perisian sistem pemodelan algebra umum sebagai alat. Objektif penyelidikan adalah; (i) Untuk membangunkan strategi kos efektif untuk pengumpulan MSW dan pengangkutan dari tampat generasi ke pelupusan / pemulihan untuk kawasan IM tipikal menggunakan pengaturcaraan linear meminimumkan kos. (ii) Untuk membangunkan satu strategi penggunaan MSW satu tempoh untuk penjanaan hasil daripada komponen MSW yang boleh dikitar semula dalam IM menggunakan alat pengoptimuman untuk memaksimumkan keuntungan. (iii) Untuk menganggarkan potensi biogas ke penjanaan elektrik daripada komponen organic MSW dalam IM. Hasilnya menunjukkan kos pengangkutan yang optimum adalah pada RM 5.97 juta setiap minggu. Jumlah MSW yang diangkut dari kawasan perbandaran ke tapak pelupusan untuk mencapai hasil yang kos efektif ialah Pasir Gudang ke Tanjung Langsat (2452 tan metrik), Kulai hingga Pekan Nenas dan Seelong (512 dan 1501 tan metrik), Pontian ke Pekan Nenas dan Seelong (1739 dan 2214 tan metrik), Johor Bahru ke Pekan Nenas, Seelong dan Tanjung Langsat (1739, 7485 dan 18 tan metrik), Johor Bahru ke Pekan Nenas, Seelong dan Tanjung Langsat (1739, 6881 dan 110 tan metrik). Jumlah trak ke setiap tapak pelupusan adalah Seelong, 988, Pekan Nenas, 313 dan Tanjung Langsat, 141. Perjalanan paling tinggi dan paling jauh adalah dari Johor Bahru ke Seelong dan Tanjung Langsat masing-masing pada 429 dan 1. Hasilnya juga memaparkan kos minimum pengasingan MSW ke dalam kitar semula ialah MYR 572,000. Komponen kitar semula tertinggi dan paling rendah ialah organik dan kaca (46 dan 19 tan metrik) pada unit pengasingan 1 dan 5. Kos elektrik yang dikurangkan daripada MSW ialah MYR 143000 / minggu. Model terdesentralisasi menunjukkan penggunaan tertinggi organik adalah di perbandaran Kulai (400 tan metrik) dan terendah di Pontian (50 tan metrik). Penjimatan kos dari 2,157,777.40 sebelum peminimuman ke 1,965,161.82 selepas peminimuman menghasilkan pengurangan sebanyak 8.9%. Model ini berupaya untuk kitar semula dan penjanaan biogas.

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%	-	Percentage
CH_4	-	Methane
CO_2	-	Carbon Dioxide
CWA	-	Community Waste Generation Area
DOC	-	Degradable Organic Carbon
EPA	-	Environmental Protection Agency
GAMS	-	General Algebraic Modelling System
IM	-	Iskandar Malaysia
IRDA	-	Iskandar Region Development Authority
IWMFs	-	Integrated Waste Management Facilities
K	-	Fraction of Kitchen Garbage in MSW
LFG	-	Landfill Gas
LP	-	Linear Programming
MILP	-	Mixed Integer Linear Programming
MSW	-	Municipal Solid Waste
P	-	Fraction of Papers in MSW
SW	-	Solid Waste
UNEP	-	United Nation Environmental Programme
W	-	Fraction of Woods/Leaves in MSW
MYR	-	Malaysian Ringgit

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Of late, lot of environmental changes has been taking place and continued despite tremendous measures taken to reduce them. The United States' Environmental Protection Agency (EPA) reported that the earth's average temperature has risen by 0.8 ^{0}C over the past century. The global temperatures are projected to rise from 1.13 to 6.42 ^{0}C over the next 100 years. This is due to the snowballing greenhouse gas (GHG) concentrations in the atmosphere. The greenhouse gas accumulation is caused by human activities such as fossil fuel burning, deforestation, inadequate and improper management of wastes of all types among others.

These problems are ascribed mainly to the rapid population explosion in one way and urbanization and industrialization on the other, which also results in the generation of thousands of tonnes of MSW daily. Although, environmental pollutions are present right from the very beginning of life, it is a very serious problem in the recent time that threatens the survival of humankind. Cities all over the world, particularly in the developing countries are facing severe environmental related challenges. The shift in the use of renewable materials obtained from agriculture and forestry products to non-renewable materials such as metals, fossil fuel-derived products and other related products, has further escalated the problem. This is due to the fact that, these products produced from the non-renewable materials are difficult for the nature to treat (EPA, 2009, Malaysia, 2010). Hence, in the interest of sustainability, clean and sanitized environment is of great concern all over the world.

Man always strives to improve his living conditions both within his immediate and larger environment. Humanity's desire to attain economic growth has led man to search, invent and establish many industries, which produce products of many different types. Via these ways and processes, natural raw materials are usually converted by these industries into different types of products. A certain percentage of these products become wastes after usage and returned to the environment in either similar or different forms causing unnecessary pollution.

People's lifestyle continues to change with the growth in their purchasing power, as it is a human nature to have the desire to change as their income increases. In general, the wealthier and developed a city is, the more wastes are produced. This is because, wastes are unavoidable products of human reality, and in most cases, the poor countries produce higher organic fractions in their wastes and rich cities tend to have more complex waste compositions that are difficult to be degraded (Vergara and Tchobanoglous, 2012). As a result, rapidly developing nations face the challenge of providing efficient services. This is because, it is labor and cost-intensive and where there is enough fund, the dearth in well-trained workers is commonplace.

In general, wastes are typically classified based on types and origin, one of such is municipal solid waste (MSW). MSW refers to the materials that are generated, collected and discarded of because of its no or less value to the generators (Castrejón-Godínez et al., 2015). This includes non-hazardous wastes generated from households, commercial establishments, institutions and non-process related industrial wastes like waste paper and paperboard. However, it excludes waste from municipal services such as water and wastewater treatment sludge's, industrial process, agricultural and mining wastes. It is typically heterogeneous in nature, comprising a mixture of different materials. Hence it is complex to manage due to the fact that its constituents and compositions vary all over (Agamuthu, 2009). The various sources of solid waste include; residential, commercial, institutional, construction and demolition, municipal services, treatment plant sites, industrial and agricultural (O'leary et al., 2002).

Municipal solid waste (MSW) is also the by-products of man's daily activities. Hence, it is inevitable as long as human beings exist on earth but can only be managed. However, just like how the botanists described weed as plants in the wrong place, so also is waste a resource, but also placed in the wrong place because many of these waste materials can be reused or recycled, thereby transforming it to be a resource for either agricultural use, industrial production or energy generation, for example, MSW has been increasingly receiving acceptance as a clean source of energy when adequately managed. It mostly contains depending on some factors significant fraction of food wastes, papers, plastics, metal, glass, wood and yard trimmings, leather and textiles (Cheng and Hu, 2010).

Furthermore, MSW is the most visible evidence which clearly tells the quality of governance of a country. The level of successes or failures on how the environment is taken care of gives to some extent, an idea of the quality of a country's governance (Ezeah and Roberts, 2014). MSW management has been a very long practice and continuously in need for improvement. The collection and disposal of MSW is the most tasking and expensive aspects in MSW management, requiring great attention from municipal authorities. Ghiani et al. (2013) are of the opinion that MSW management is an increasingly complex task, because it consumes a huge amount of resources and having a major environmental impact. Its generation keeps on skyrocketing at an alarming rate (Agamuthu, 2009, Manaf et al., 2009a, Begum and Pereira, 2011).

Apart from its management being costly in most nations of the world, the waste are inappropriately disposed and mostly in open dumpsites. In the landfills and the dumpsites, they decompose to produce landfill gas (LFG), and traces of other gases thereby endangering life and the environment at large. Government officials worldwide, more particularly in developing nations are struggling to identify and implement the most appropriate MSW management technologies (Johari et al., 2012a).

Effective waste management strategies depend on local waste characteristics, which may vary with culture, climate, and socioeconomic variables, and institutional capacity (Vergara and Tchobanoglous, 2012). The 2006 estimation by United Nations Environmental Programme (2009) put the total quantity of MSW generated world over reaching 2.02 billion tonnes, representing about 7% of the annual increase since 2003. In addition, the United Nations Environmental Programme (UNEP, 2009) estimated that between 2007 and 2011, the global generation of municipal waste would increase by 37.3%, which is equivalent to about 8% increase per year (Paul et al., 2012). It was also estimated in 2012 that, globally about 3 billion urban residents generated waste at a rate of 1.2 kg per person per day which is equivalent to 1.3 billion tonnes per year. By 2025, this will likely increase to 4.3 billion urban residents generating about 1.42 kg/capita/d of waste, that is 2.2 billion tonnes per year (Hoornweg and Bhada-Tata, 2012).

The problems of MSW management were identified in years past and many are ongoing subject of research using modern tools. Many scholars have developed different mathematical models that dealt with MSW generations, collection and transportation, allocations to facilities, facility locations, capacities and expansion patterns. Most of the models were developed using linear, nonlinear and mixed integer linear programs. Their objectives is to minimize economic cost and or to minimize environmental impacts like the release of greenhouse gas (GHG) in the forms of emissions from waste collection vehicles or methane from Landfills in to the environment (Ahluwalia and Nema, 2011, Costi et al., 2004, Santibañez-Aguilar et al., 2014).

In the case of Malaysia, the rapidly growing economy and rise in population, has come along with a cost, negative in nature. That is, the corresponding increase in the generation of solid waste (Kathiravale, 2003), to the extent that managing these solid wastes well and affordably became a very serious issue to waste managers and policy makers (Manaf et al., 2009a). This worldwide trend follows a similar pattern in Malaysia to the extent that the 30,000 tonnes/day, which was earlier on, estimated to be produced in 2020, is about being realized right ahead of the expected period (Agamuthu and Fauziah, 2011). In Iskandar Malaysia, one of the regions proposed by the government to attain a world class development, situated in the southernmost part of the Peninsular Malaysia, about 965,875 tonnes of combined residential, commercial and industrial solid waste was produced in the year 2010. This has been estimated to reach about 2,259,048 tonnes in the year 2025 (Malaysia, 2010).

Presently, the composition of the wastes shows that about 40-60% is of organic origin, containing high amount of moisture content and bulk density which makes it difficult to ordinarily handle and dispose. About 90 - 95% of the collected wastes is still disposed of by landfilling and a little fraction of about 5 -10% been recycled despite the fact that 70 - 80% of the wastes are recyclable by their nature (Agamuthu, 2009, Ngoc and Schnitzer, 2009).

Iskandar Malaysia (IM) is currently one of the fastest developing regions in the whole of Malaysia. In its effort to ensure that development is spread all over the country, the government considered this region as one of the choice areas and was established in 2006. The decision for such was conceived more than a decade now, back in the year 2000. Although, this plan is to cover the whole of Malaysia, IM is far leading ahead because it is more developed, industrialized, and richer than the average of Malaysia in general. The government planned to make it to be a region of world class standard. The 2015 population estimate was about two million, which has been projected to reach about three million in 2025. The residential solid wastes generation in 2015 was 896,463 tonnes per year and was estimated to reach about 1.5 million tonnes per year. The commercial and industrial wastes estimation for 2015 and 2025 are 395,259 and 681,645 tonnes per year respectively (Malaysia, 2010).

In order to achieve this stated developmental target in a sustainable way, adequate measures need to be put on ground especially concerning the negative effects of the proposed development to the environment. These effects may include climate change, rise in sea level, since it is situated close to the sea, pollution of air, land and water sources as a result of its proximity to water bodies and also considering the increasing level of industrialization (Hezri and Nordin Hasan, 2006, Shekdar, 2009) To minimize these effects, the need to adopt certain management measures such as prolonging the deliverable age of a products and turning wastes in to a new product is of utmost importance especially before it gets to a new consumer (Khoo et al., 2011). The simplest and most effective way of dealing with wastes is to ensure that it does not get generated at the first place. The cost of waste management will be the minimum when the volume of waste to be disposed is also reduced. In addition, small volume of waste contributes to less impact (health hazards, environmental pollution) and would require small land for disposal.

If most of the waste could be diverted for material and resource recovery, then the volume requiring disposal would be minimized, leading to the attainment in cost savings. Hence, revenue could be generated from the sale of the recovered materials and energy resources, which could be utilized to fund the waste management. To improve the effectiveness of MSW management, optimization techniques were found to be very effective. Many MWM management problems have been solved with the development and implementation of optimization models (Abounajm and Elfadel, 2004, Arribas et al., 2010, Costi et al., 2004, Fiorucci et al., 2003, Karadimas et al., 2005, Li and Huang, 2006, Minciardi et al., 2008). Johansson (2006) demonstrates that adopting a dynamic scheduling and routing policies when developed and implemented was found to yield a better result that lowers operating costs, reduce collection and haulage distances, reduces labour working hours and its cost from the ones resulting from static policies with fixed routes and pre-determined pick-up frequencies that are usually employed by many waste collection operators.

Waste problems and issues urgently need to be managed. There are various methods of management; either using technologies like the use of anaerobic digestion, incineration, sanitary landfills, etc or by using management tools (i.e. planning, etc). In order to successfully plan and operate solid waste management systems, knowledge about the sources, generation process, waste quantities produced, current management methods and the need for exploring alternative method of disposal other than landfilling is greatly essential (Johari et al., 2012a). On the other hand, awareness needs to be extensively created for buying materials that are environmentally friendly through careful purchasing initiatives such as reducing sources of waste, encouraging reuse and recycling, etc.

1.2 Problem Statement

Habitat (2008), estimated and reported that almost half of the world's population are living in urban areas. It was also reported that by the middle of this century, almost all the regions of the world would become urban areas. Many cities and regions in the developing countries continue to grow due to population explosion, industrialization and improving living standards. This greatly contributes to increase in the quantities and complexity of the MSW produced contrary to what was produced in the past decades. These huge amounts if left unattended can be potential sources of damage to the environment. Therefore, the provision of effective MSW management is an absolute necessity both in the interest of public health, climate change and environmental sustainability.

Agamuthu and Fauziah (2011) has reported that the worldwide solid waste generation to increase from its year 2000 amount of 9.0 million tonnes to about 10.9 million tonnes in 2010. They further stated that, it would increase to about 12.8 million tons in 2015 and finally to about 15.6 million tonnes in 2020. In the case of Malaysia, the rise in its standard of living has over the years resulted to the production of huge quantity of waste, making its proper management difficult and so also in many other developing countries.

Prior to the early seventies, solid waste management was not a serious issue in Malaysia. It begun to draw more attention when the country started its developmental stride, which in a way make the amount of waste generated to increase. The per capita per day waste generation rate in the year 2010 for Iskandar Malaysia was estimated at 1.06 kg, and about 965,875 tonnes of combined residential, commercial and industrial was generated. On the average, about 870 t/d of solid waste was produced. This amount has also been estimated to increase to 1,720,927 tonnes in the year 2020 and continues to increase further (Malaysia, 2010). Malaysia's main disposal option has been landfilling, a research into alternatives other than or in addition to the landfilling is a continuously and tirelessly sought up till now since managing the landfill area is very costly and not environmentally sound and sustainable (Agamuthu and Fauziah, 2008, Ngoc and Schnitzer, 2009). Siting and maintaining landfills can be sustainable only if the environmental and economic issues are well considered.

Most of the municipal councils spent greater than 50% of their budget on the management of the wastes (Manaf et al., 2009b). It was also reported that the amount of money needed to manage landfills alone in Malaysia have been estimated at RM10,000 for landfills in the rural areas and the ones in cities cost between RM30,000 – RM40,000 on monthly basis. The government spent close to RM900 million annually on the collection and management of solid waste (Borneopost, 2010). Apart from the cost implications, the country faces environmental threat due to lack of efficient management system.

Approximately 75% of the generated solid waste produced is collected, and about 80 - 90% of it is disposed of in landfills with only about 5% recycled (Ngoc and Schnitzer, 2009). However, in 2020, Malaysia committed to meeting the 22 per cent recycling rate as the amount of solid waste produced each year drastically increases. In view of that, a new integrated MSW management which is currently still unavailable in the region of Iskandar Malaysia (IM) is to be proposed. This new model would help policy makers in implementing the best practices that will minimize total cost and environmental pollution for Iskandar Malaysia.

Abushammala et al. (2010), stated that the solid waste disposed of in the landfills decompose anaerobically thus producing landfill gas (LFG) containing approximately 50 - 60% methane (CH_4) and 30 - 40% carbon dioxide (CO_2) by volume. They further stated that CH_4 has a global warming potential of about 21 times greater than CO_2; thus, posing serious environmental problem. Of the estimated, less than 5% of the global GHG emissions are due to waste management and only 9% of methane is released. This landfill gas emission is a threat to the environment which can result in fire incidences or explosions. In some areas, the landfills give off bad odors due to lack of daily cover of the deposited waste hence creating a very nice environment for the growth and multiplication of disease vectors such as rats, flies and serve as hideouts for reptiles. These hazards can be worst especially when the landfill is located near areas with high population density and/ high concentration of industries such as Seelong in Johor Bahru and Tanjung Langsat in Pasir Gudang (Ahmed et al., 2014).

Globally, attention is nowadays given to climate changes happening and measures and new policies are considered to divert towards renewable energy in order to minimize GHG emissions. Ho et al. (2009) estimated the per capita CO_2 emission in IM as 9.3 tonne, which is greater than the national average of 5 tonne. Also, Peterson et al. (2010) asserted the fact that the disposal of solid waste alone contributes more than 12% of the anthropogenic methane, and therefore, ranked as the fourth largest source of non-carbon dioxide GHG emissions to the environment. In order to forestall or minimize these impacts to the environment, many countries are aiming to reduce the biodegradable content wastes and its disposal into landfill.

In order to transform Iskandar Malaysia (IM) to a world class city as planned by the Malaysian government, there is a great need for a sustainable strategy like the ones found in some of the developed cities of the world like London, Singapore, and others. In view of that, efficient collection and transportation of MSW system, processing and utilization of the recyclable components and the utilization of the organic components for electricity was found to be not available in IM. It was on these regards that the research studied how economically viable the system is by developing three mathematical models of MSW collection and transportation, recycling and biogas to electricity generation potentials of the MSW in IM.

1.3 Aim and Objective

The aim of the research is to select among several other options the best combinations of MSW management strategy for Iskandar Malaysia. An optimization software, General Algebraic Modeling System (GAMS) is used to enhance accuracy of the process. The objectives are as follows:

i. To develop a linear programming model for sustainable MSW collection and transportation from points of generation to disposal / recovery for Iskandar Malaysia with focus on cost minimization.
ii. To investigate the recyclable components of MSW in Iskandar Malaysia and develop a linear programming model for the utilization of the recyclable components to maximize profit.
iii. To develop a mathematical model for electricity generation from the organic components of the MSW in Iskandar Malaysia.

1.4 Scope of the Research

The study is limited to proposing a solution to the problems of MSW management in Iskandar Malaysia region with a view for examining the following:

i. The current MSW sources, quantities and compositions will be identified and assessed. Also, the number, size/capacities, average distance, locations of facilities and the management cost of the existing methods will be determined.
ii. The study will determine how value would be restored to the MSW in terms of material recycling, compost production for use in gardens and electricity generation from biogas produced via anaerobic digestion of organic wastes. It will also include the landfilling of the non-utilizable wastes.
iii. Mixed integer linear programming method will be used in developing the optimization models and will be coded in General Algebraic Modelling System (GAMS).
iv. The MSW characterization used for the study is for Malaysia in general and not only for Iskandar Malaysia.

1.5 Significance of the Study

The use of mathematical modelling to predict a future event iteratively is essential as it gives the likely outcome of an event. This research will assist policy makers to identify the cost competitive strategy for implementation in order to reduce generation and improve the management of MSW in Iskandar Malaysia. These models also, will assist in improving and raising the aesthetic value of Iskandar Malaysia thereby giving visitors the impression that good governance exist in the region, hence attracting investors to come and invest. In addition, extra revenue could be generated which could be used to offset part of the costs of management. It can also be extended to other parts of Malaysia and other countries all over the world.

1.6 Organization of the Study

The research work will be presented in the following chapters:

Chapter One: In this chapter, the research work was introduced by giving highlights of the problem, the objectives, significance and the scopes are provided.

Chapter Two: General review of relevant literatures on solid wastes, solid waste management, MSW and its management was conducted. Review was also conducted for Malaysia and narrowed down to Iskandar Malaysia, which is the research area. Previous works on modelling and optimization of MSW management and a brief on the modelling software used, that is, GAMS was presented in this chapter.

Chapter Three: This chapter presents the methodology used for carrying out the research work, which includes data collection, the formulation of the model, and explanations on how the GAMS software would be used.

Chapter Four: The results of the research were presented and discussed referring where necessary to the literatures, in this chapter.

Chapter Five: Conclusions and recommendations on the research findings are presented in this chapter.

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APPENDIX A

WASTE COLLECTION OPTIMIZATION

MODEL SYMBOLS AND DEFINATIONS

M – Municipal administrative areas in Iskandar Malaysia for waste collections

M1- Pasir Gudang (MPPG)

M2- Kulai (MPKu)

M3– Pontian (MDP)

M4- Johor Bahru (MBJB)

M5- Johor Bahru Tengah (MPJBT)

L- Landfill sites for waste disposal

L1- Pekan Nenas

L2- Seelong

L3- Tanjung Langsat

CWA- Community waste collection areas (CWA1-CWA28)

T- Truck type for waste collection (T1, T2)

LData (L,*) - Landfill data

Capwkton - Capacity-per-week

OpCton - Processing cost-per-ton in (MYR)

RData (i, k) - Community waste collection areas road Network (km) in each administrative area (Google GIS data)

LDist (i, L, k) - Community waste collection areas to Landfill road Distance (km)

CDen (i, k) - Distance between waste collection points in community areas (km)

LocProd (i, k) - Waste Production per week at each waste collection points in community areas (ton)

Truck(T,*) - Truck capacity fuel use and depreciation data

Capton – capacity per ton

capvol – capacity in volume

fuIdle – fuel consumption while idling

fuMov – fuel consumption when moving

depwk – depreciation per week

coltime - Waste collection time by truck per location in hrs /0.083/

udump - Unload time at the disposal site in hrs /0.183/

cspeed - Collection speed in km per hr /5/

tspeed - Travelling speed in km per hr /55/

coleff - Truck capacity utilization /0.75/

emply - Number of workers per truck /3/

wkwage - Average workers weekly wage /1000/

fcost - Cost of diesel fuel per liter in MYR /2.4/

period - Cost optimization period in weeks /1/

locs(i, k) - Number of waste collection points in each community area

loc2locTime(i, k) - Travel time between waste collection points

trips(i, k) - Number of truck trips needed to evacuate waste generated in area per week

idleFcost(i, k) - Idle fuel cost used during waste collection

colFcost(i, k) - Fuel cost used in travelling between waste collection points

wagecost - Employee weekly wages per truck (3 workers per truck) equal pay

travcost - Truck travel fuel cost per hour in MYR

tdumpcost - Truck fuel cost for waste disposal at landfill site

Capacity(i, L) - Observe landfill processing capacity

Supply(i, k) - Observe waste Generation from community waste collection areas.

```
* Model of waste collection for Iskandar area in Johor bahru

SETS M Municipal administrative areas for waste collection
      / M1    Pasir Gudang (MPPG)
        M2    Kulai (MPKu)
        M3    Pontian (MDP)
        M4    Johor Bahru (MBJB)
        M5    Johor Bahru Tengah (MPJBT)/

     L Landfill sites for waste disposal
       / L1    Pekan Nenas
         L2    Seelong
         L3    Tanjung Longsat /

     CWA Community waste collection areas
       / CWA1*CWA28 /

     T Truck Type for waste collection
      / T1
        T2 /;

Table LData (L,*) Landfill data (Capacity-per-week and Processing cost-per
-ton in MYR)

```

```
      Capwkton  OprCton
 L1  1750      30.0
 L2  9800      30.0
 L3  8400      30.0


TABLE MData(M,CWA) Community waste collection areas road Network (km) in each administrative area (Google GIS data)

        CWA1    CWA2    CWA3    CWA4    CWA5    CWA6    CWA7    CWA8    CWA9    CWA10   CWA11   CWA12   CWA13   CWA14   CWA15   CWA16   CWA17   CWA18   CWA19   CWA20   CWA21   CWA22   CWA23   CWA24   CWA25   CWA26   CWA27   CWA28
 M1     32.84   6.22    25.84   16.99   21.06   37.9    44.89   5.48    24.53   26.24   50.66   70.95   42.37   57.33   0.97    16.19   14.32   57.13   36.29

 M2     70.89   54.93   49.63   4.69    9.18    20.54   75.78   34.7    15.92   25.29   19.18

 M3     40.03   28.25   46.6    24.57   26.51   126.78

 M4     8.28    67.95   0       0       18.38   17.14   0       0       83.65   0       25.8    253.44  92.37   0       231.11  204.49  0       52.11   91.11   61.82   0       87.36   118.05  46.48   121.39  0       0       0

 M5     0       0       136.37  11.25   0       0       100.49  73.34   0       90.94   0       0       0       231.03  0       0       81.71   0       0       0       76.39   0       0       0       0       57.32   36.38   325.43
 ;



TABLE LDist(M,L,CWA) Community waste collection areas to Landfill road Distance (km)

          CWA1    CWA2    CWA3    CWA4    CWA5    CWA6    CWA7    CWA8    CWA9    CWA10   CWA11   CWA12   CWA13   CWA14   CWA15
```

CWA16 CWA17 CWA18 CWA19 CWA20 CWA21 CWA22 CWA23
CWA24 CWA25 CWA26 CWA27 CWA28

M1.L1 54.9 73.1 71.7 74.1 69.3 70.0 57.6
66.5 68.2 69.0 72.3 72.8 64.1 61.7 49.0
61.7 86.7 74.2 89.4

M1.L2 41.6 46.5 45.1 49.1 42.7 43.3 44.3
39.9 41.5 42.3 37.8 37.9 37.5 36.8 34.6
35.1 35.4 47.6 65.0

M1.L3 15.2 13.4 11.1 9.0 13.3 11.9 12.1
17.9 15.1 13.4 16.5 15.3 20.6 20.8 23.7
24.1 17.7 8.3 2.5

M2.L1 31.5 30.4 27.8 29.4 27.2 24.9 26.3
23.0 22.8 26.8 29.2

M2.L2 20.4 23.7 23.9 20.4 26.5 27.4 24.5
27.7 28.6 28.7 24.5

M2.L3 56.0 63.4 63.6 59.0 65.9 66.7 63.3
63.0 64.6 66.8 60.2

M3.L1 32.5 30.1 26.8 26.1 24.2 2.2

M3.L2 79.9 77.3 74.0 73.3 71.4 44.3

M3.L3 117.0 115.0 112.0 111.0 109.0 71.0

M4.L1 31.6 28.3 25.0 21.3 22.0 25.6 16.2
25.0 29.5 36.5 31.7 10.1 17.5 24.5 32.6
38.9 24.8 39.1 38.9 40.8 18.2 41.5 62.2
58.3 36.8 18.7 20.3 25.3

M4.L2 53.0 55.9 52.7 48.8 46.0 45.7 45.7
37.4 33.4 31.6 35.6 42.1 45.7 25.9 21.1
23.6 27.0 27.9 28.8 33.3 33.4 16.1 26.2
33.3 9.6 33.9 30.8 30.5

M4.L3 65.5 68.2 65.0 61.1 53.6 53.5 56.0

```
   51.1   47.9   45.4   43.3   57.9   80.3   53.1   42.4
     34.1   54.3   36.2   29.1   38.8   60.6   41.3   40.9
     26.3   59.6   61.1   58.0   49.4

M5.L1   0   0   25   21.3   0   0   16.2
   25   0   36.5   0   0   0   24.5   0
     0   24.8   0   0   0   18.2   0   0
     0   0   18.7   20.3   25.3

M5.L2   0   0   52.7   48.8   0   0   45.7
   37.4   0   31.6   0   0   0   25.9   0
     0   27   0   0   0   33.4   0   0
     0   0   33.9   30.8   30.5

M5.L3   0   0   65   61.1   0   0   56
   51.1   0   45.4   0   0   0   53.1   0
     0   54.3   0   0   0   60.6   0   0
     0   0   61.1   58   49.4;



TABLE CDen(M,CWA) Distance between waste collection points in community ar
  eas (km)

      CWA1  CWA2  CWA3  CWA4  CWA5  CWA6   CWA7  CWA8  CWA9  CWA
  10  CWA11  CWA12  CWA13  CWA14  CWA15  CWA16  CWA17  CWA18  CWA19  CWA20
  CWA21  CWA22 CWA23   CWA24 CWA25  CWA26  CWA27  CWA28
M1  1.5   1.5   1.5   0.025  0.025  0.025   0.025  0.025  0.025  0.0
  25  0.025  0.025  0.025  0.025  0.025  0.025  0.025  0.025

M2  0.025  0.025  0.025  0.025  0.025  0.025   0.025  0.025  0.025  0.0
  25  0.025

M3  0.025  0.025  0.025  0.025  0.025  0.025

M4  0.025  0.025  0.025  0.025  0.025  0.025   1.5   0.025  0.025  0.0
  25  0.025  0.025  0.025  0.025   1.5   0.025  0.025  0.025  0.025  0.025
  0.025  1.5   0.025   1.5   0.025  0.025  0.025  0.025

M5  0.025  0.025  0.025  0.025  0.025  0.025   1.5   0.025  0.025  0.0
```

```
25  0.025  0.025  0.025  0.025   1.5   0.025  0.025  0.025  0.025  0.025
0.025  1.5   0.025   1.5   0.025  0.025  0.025  0.025;



TABLE LocProd(M,CWA) Waste Production per week at each waste collection po
ints in community areas (tonnes)

      CWA1   CWA2   CWA3   CWA4   CWA5   CWA6   CWA7   CWA8   CWA9   CWA10
  CWA11  CWA12  CWA13  CWA14  CWA15  CWA16  CWA17  CWA18  CWA19  CWA20
CW
A21  CWA22  CWA23  CWA24    CWA25    CWA26    CWA27   CWA28
  M1  0.15   0.15   0.15   0.05   0.05   0.05   0.1    0.1    0.1    0.1
  0.1    0.1    0.1    0.1    0.1    0.1    0.1    0.05   0.15

  M2  0.094  0.094  0.094  0.094  0.094  0.094  0.094  0.094  0.094  0.094
  0.094

  M3  0.25   0.25   0.25   0.25   0.25   0.25

  M4  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144
  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.
144  0.144  0.1    0.188    0.144    0.144    0.144   0.144

  M5  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144
  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.144  0.
144  0.144  0.1    0.188    0.144    0.144    0.144   0.144;



TABLE Truck(T,*) Truck capacity fuel use and depreciation data

       capton   capvol   fuIdle   fuMov   depwk
  T1   18.3     24.5     3.15     0.335   16.88
  T2   25.5     32.0     4.1      0.55    18.75;

SCALARS
 coltime    Waste collection time by truck per location in hrs  /0.083/
 udump      Unload time at the disposal site in hrs  /0.183/
 cspeed     Collection speed in km per hr  /5/
 tspeed     Travelling speed in km per hr  /55/
 coleff     Truck capacity utilization /0.75/
```

```
emply      Number of workers per truck /3/
wkwage     Average workers weekly wage /1000/
fcost      Cost of diesel fuel per liter in MYR /2.4/
period     Cost optimization period in weeks /1/;
PARAMETERS
locs(M,CWA)           Number of waste collection points in each community area
loc2locTime(M,CWA)    Travel time between waste collection points
trips(M,CWA)          Number of truck trips needed to evacuate waste generated in area per week
idleFcost(M,CWA)      Idle fuel cost used during waste collection
colFcost(M,CWA)       Fuel cost used in travelling between waste collection points
wagecost              Employee weekly wages per truck (3 workers per truck) equal pay
travcost              Truck travel fuel cost per hour in MYR
tdumpcost             Truck fuel cost for waste disposal at landfill site;
locs(M,CWA)(CDen(M,CWA) ne 0) = MData(M,CWA)/CDen(M,CWA);
loc2locTime(M,CWA) = CDen(M,CWA)/cspeed;
trips(M,CWA) = (LocProd(M,CWA)*locs(M,CWA))/(Truck('T1','capton')*coleff);
idleFcost(M,CWA) = locs(M,CWA)*coltime*Truck('T1','fuIdle')*fcost;
colFcost(M,CWA) =  (locs(M,CWA)-1)*loc2locTime(M,CWA)*Truck('T1','fuMov')*fcost;
wagecost = wkwage*emply;
travcost = (Truck('T1','fuMov')*fcost)/tspeed;
tdumpcost = udump*Truck('T1','fuIdle')*fcost;
Variables
x(M,L,CWA)  Number of truck trips of waste from community areas to landfill sites
Z         Total transport cost;
Integer variable x;
Equations
```

```
160   Cost              Define objective cost function
161   Capacity(M,L)      Observe landfill processing capacity
162   Supply(M,CWA)        Observe waste Generation fron community waste collec
     tion areas;
163
164
165   Cost..            Z =e= Sum((M,L), Sum(CWA, x(M,L,CWA)*period*((LDist(M,
     L,CWA)*travcost)+colFcost(M,CWA)+idleFcost(M,CWA)+tdumpcost)+wagecost));
166   Capacity(M,L)..    Sum(CWA, x(M,L,CWA)*Truck('T1','capton')) =l= LData(L,
     'Capwkton')*period;
167   Supply(M,CWA)..      Sum(L, x(M,L,CWA)) =g= trips(M,CWA)*period;
168
169  Model WCO /all/;
170
171  Solve WCO using MIP minimizing z;
172
173  Display trips, x.l;
```

MODEL STATISTICS

BLOCKS OF EQUATIONS 3 SINGLE EQUATIONS 156

BLOCKS OF VARIABLES 2 SINGLE VARIABLES 421

NON ZERO ELEMENTS 1,261 DISCRETE VARIABLES 420

GENERATION TIME = 0.031 SECONDS 4 MB 24.5.6 r55090 WEX-WEI

EXECUTION TIME = 0.031 SECONDS 4 MB 24.5.6 r55090 WEX-WEI

GAMS 24.5.6 r55090 Released Nov 27, 2015 WEX-WEI x86 64bit/MS Windows 01/16/19 07:57:52

Page 5

WCO MODEl

Solution Report SOLVE WCO Using MIP From line 171

S O L V E S U M M A R Y

MODEL WCO OBJECTIVE Z

TYPE MIP DIRECTION MINIMIZE

SOLVER CPLEX FROM LINE 171

**** SOLVER STATUS 1 Normal Completion

**** MODEL STATUS 1 Optimal

**** OBJECTIVE VALUE 1965161.8191

RESOURCE USAGE, LIMIT 0.280 1000.000

ITERATION COUNT, LIMIT   0   2000000000

IBM ILOG CPLEX   24.5.6 r55090 Released Nov 27, 2015 WEI x86 64bit/MS Windows
--- GAMS/Cplex Link licensed for continuous and discrete problems.
Cplex 12.6.2.0

APPENDIX B

RECYCLING OPTIMIZATION

MODEL TERMS AND DEFINATIONS

L - index for MSW locations /L1*L5/

L1 - Pasir Gudang (MPPG)

L2 - Kulai (MPKu)

L3 - Pontian (MDP)

L4 - Johor Bahru (MBJB)

L5 - Johor Bahru Tengah (MPJBT)

i - MSW compositions /i1*i6/

1 organics

2 Paper

3 Plastic

4 Metal

5 Glass

6 Others

s - MSW separation point /s1*s3/

t - technologies considered /t1*t3/

1 composting

2 recycling

3 landfilling;

k - value added products /k1*k5/

1 compost

2 paper

3 plastics

4 metal

5 glass;

USepCost - Unit separation cost in MYR per tonne /5/;

Fls(l,s) - waste availability at source

Com(l,i) - waste compositions at source locations

UTrCost(L,s) - Unit transportation cost in MYR per tonne of wastes from source l to sorting point s

UTrCost2(s,t) - Unit transportation cost in MYR per ton of sorted wastes from sorting point s to technologies t

UCOMCost(t) - Unit capital operating and maintenace cost of technologies

URev(k) - Unit revenue generation in MYR per ton

yp(i,t,k) - percent concentration of categories i converted to k products under technology t

TrCost - transportation cost in MYR per ton from source locations to sorting point s1

SepCost - separation cost in MYR per ton of wastes

TrCost2 - transportation cost from sorting point to technologies

COMCost(t) - capital operating and maintenance cost of technologies

REV(k) - Revenue generated for each k

Fls(L,s) - Flowrates of mixed wastes from source locations to sorting point

Fis(i,s) - Flowrate of wastes components (i)of wastes going into sorting unit (s1)

Fots(i,s) - flowrate of wastes components (i) going out of sorting unit (s1)

Fst(i,s,t) - flowrate of waste components (i) going to technologies from sorting point

Fint(i,t) - flowrate of the resource materials going into technologies

Fott(t,k) - flowrate of materials going out of technologies after conersion

FP(k) - flowrate of materials converted to products k

i1 - amount of organics

SETS

L index for MSW locations /L1*L5/

*L1 Pasir Gudang (MPPG)

*L2 Kulai (MPKu)

*L3 Pontian (MDP)

*L4 Johor Bahru (MBJB)

*L5 Johor Bahru Tengah (MPJBT)

i MSW compositions /i1*i6/

*1 organics

*2 Paper

*3 Plastic

*4 Metal

*5 Glass

*6 Others

s MSW separation point /s1*s3/

t technologies considered /t1*t3/

```
*1 composting
*2 recycling
*3 landfilling;

k value added products /k1*k5/
*1 compost
*2 paper
*3 plastics
*4 metal
*5 glass;
;

SCALAR
USepCost    Unit separation cost in MYR per ton /5/;

PARAMETER
Fls(l,s) waste availability at source/
L1.s1       50
L1.s2       30
L1.s3       40
L2.s1       30
L2.s2       25
L2.s3       35
L3.s1       10
L3.s2       30
L3.s3       20
L4.s1       25
L4.s2       30
L4.s3       30
L5.s1       35
L5.s2       25
L5.s3       20      /

Com(l,i) waste compositions at source locations/
L1.i1     0.40
L1.i2     0.10
L1.i3     0.20
L1.i4     0.15
```

L1.i5	0.10
L1.i6	0.05

L2.i1	0.30
L2.i2	0.20
L2.i3	0.25
L2.i4	0.10
L2.i5	0.05
L2.i6	0.10

L3.i1	0.20
L3.i2	0.15
L3.i3	0.10
L3.i4	0.15
L3.i5	0.10
L3.i6	0.30

L4.i1	0.20
L4.i2	0.20
L4.i3	0.20
L4.i4	0.20
L4.i5	0.20
L4.i6	0.20

L5.i1	0.30
L5.i2	0.30
L5.i3	0.30
L5.i4	0.30
L5.i5	0.30
L5.i6	0.30/

UTrCost(L,s) Unit transportation cost in MYR per ton of wastes from source l to sorting point s/
L1.s1	10
L2.s1	10
L3.s1	10
L4.s1	10
L5.s1	10
L1.s2	10
L2.s2	10
L3.s2	10
L4.s2	10
L5.s2	10
L1.s3	10
L2.s3	10
L3.s3	10
L4.s3	10
L5.s3	10
/

UTrCost2(s,t) Unit transportation cost in MYR per ton of sorted wastes from sorting point s to technologies t/

s1.t1 10
s1.t2 10
s1.t3 10
s2.t1 10
s2.t2 10
s2.t3 10
s3.t1 10
s3.t2 10
s3.t3 10
/

UCOMCost(t) Unit capital operating and maintenace cost of technologies/

t1 20
t2 30
t3 5
/

URev(k) Unit revenue generation in MYR per ton/

k1 5
k2 8
k3 7
k4 2
k5 1
/

Table

yp(i,t,k) percent concentration of categories i converted to k products under technology t

	k1	k2	k3	k4	k5
i1.t1	0.9	0	0	0	0
i2.t1	0.2	0	0	0	0
i3.t1	0.1	0	0	0	0
i4.t1	0	0	0	0	0
i5.t1	0	0	0	0	0
i6.t1	0.3	0	0	0	0
i1.t2	0	0	0	0	0
i2.t2	0	0.9	0	0	0
i3.t2	0	0	0.8	0	0
i4.t2	0	0	0	0.9	0
i5.t2	0	0	0	0	1
i6.t2	0	0	0	0	0.3
i1.t3	0	0	0	0	0
i2.t3	0	0	0	0	0
i3.t3	0	0	0	0	0
i4.t3	0	0	0	0	0
i5.t3	0	0	0	0	0
i6.t3	0	0	0	0	0

;

```
POSITIVE VARIABLES

TrCost          transportation cost in MYR per ton from source locations to sorting point s1
SepCost         separation cost in MYR per ton of wastes
TrCost2         transportation cost from sorting point to technologies
COMCost(t)      capital operating and maintenance cost of technologies
REV(k)          Revenue generated for each k
*Fls(L,s)       Flowrates of mixed wastes from source locations to sorting point
Fis(i,s)        Flowrate of wastes components (i)of wastes going into sorting unit (s1)
Fots(i,s)       flowrate of wastes components (i) going out of sorting unit (s1)
Fst(i,s,t)      flowrate of waste components (i) going to technologies from sorting point
Fint(i,t)       flowrate of the resource materials going into technologies
Fott(t,k)       flowrate of materials going out of technologies after conersion
FP(k)           flowrate of materials converted to products k
i1              amount of organics
;

VARIABLE
TC total cost;


EQUATIONS
obj
eqn2
eqn3
eqn4
eqn5
eqn6
*eqn7
eqn8
eqn9
eqn10
eqn11
eqn12
eqn13

;

obj..          TC =e= TrCost + SepCost + TrCost2 + sum((i,t),Comcost(t)) - sum(k,Rev(k));
eqn2..         TrCost =e= sum ((L,s),Fls(L,s)*UTrCost(L,s));
eqn3..         SepCost =e= sum((L,s),Fls(L,s)*USepCost);
eqn4(i)..      TrCost2 =e= sum((s,t),Fst(i,s,t)*UTrCost2(s,t));
eqn5(s,t)..    COMCost(t)=e= sum(i,Fst(i,s,t)*UCOMCost(t));
eqn6(i,k)..    Rev(k) =e= sum (t,Fott(t,k)*URev(k));
eqn8(i,s)..    Fis(i,s) =e= sum((L),Fls(L,s)*Com(L,i));
eqn9(i,s)..    Fis(i,s) =e= sum (t,Fst(i,s,t));
eqn10(i,t)..   Fint(i,t) =e= sum (s,Fst(i,s,t));
eqn11(t,k)..   Fott(t,k) =e= sum(i,Fint(i,t)*yp(i,t,k));
eqn12(k)..     FP(k) =e= sum(t,Fott(t,k));
```

```
eqn13..        i1 =e= 0.7;

MODEL          MSWMmodel /all/;
SOLVE          MSWMmodel using lp minimizing TC;
DISPLAY        TC.l;MODEL STATISTICS
```

MODEL STATISTICS

```
BLOCKS OF EQUATIONS         12     SINGLE EQUATIONS          96
BLOCKS OF VARIABLES         12     SINGLE VARIABLES         142
NON ZERO ELEMENTS          413

GENERATION TIME      =        0.016 SECONDS      4 MB  24.5.6 r55090 WEX-WEI
EXECUTION TIME       =        0.016 SECONDS      4 MB  24.5.6 r55090 WEX-WEI
GAMS 24.5.6  r55090 Released Nov 27, 2015 WEX-WEI x86 64bit/MS Windows 01/16/19
08:55:36 Page 5
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Solution Report     SOLVE MSWMmodel Using LP From line 219


     S O L V E      S U M M A R Y

     MODEL   MSWMmodel          OBJECTIVE  TC
     TYPE    LP                 DIRECTION  MINIMIZE
     SOLVER  CPLEX              FROM LINE  219

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      1 Optimal
**** OBJECTIVE VALUE          572500.0000

 RESOURCE USAGE, LIMIT          0.000      1000.000
 ITERATION COUNT, LIMIT         0    2000000000

IBM ILOG CPLEX   24.5.6 r55090 Released Nov 27, 2015 WEI x86 64bit/MS Windows
Cplex 12.6.2.0
```

APPENDIX C

BIOGAS AND ELECTRICITY GENERATION OPTIMIZATION

MODEL TERMS AND DEFINATIONS
M - index for MSW (organics) in municipal area /M1*M5/
M1 - Pasir Gudang (MPPG)
M2 - Kulai (MPKu)
M3 - Pontian (MDP)
M4 - Johor Bahru (MBJB)
M5 - Johor Bahru Tengah (MPJBT)
i - MSW (organics) generation sources in each municipal area /i1*i3/
j - processing plant ppf situated in each of the municipal area /j1,j2,j3,j4,j5/
k - centralized processing plant cpp /k/
cfb - MSW (organics) to biogas conversion factor at plants /0.45/
cfe - biogas to electricity conversion factor at plants /0.75/
Fi(i,M) - MSW (organics) availability in kg at source i of each of the municipal area
UColTrCost1 - Unit collection and transportation cost in MYR per ton of wastes from source to the plants respectively /10/
UColTrCost2 - Unit collection and transportation cost in MYR per ton of wastes from source to the plants respectively
UPlantCOST - Unit plant cost (capital OM) of plants at each of the municipal areas and the central processing point in MYR /40/
UelectGenCOST - unit electricity production cost in MYR/3/
UelectSalePrice - unit electricity saling price in MYR KWh/5/
CAP (j) - Capacities in tons of the processing plants in the municipal area
Capk - Capacity in tons of the central processing plants
Fij(i,j,M) - amount of MSW (organics) taken from the souces i to plant j within the municipal areas
Fik(i,k,M) - amount of MSW (organics) taken from the souces i in all the five municipal areas to the central processing plant k
Fj(j,M) - amount of MSW (organics) processed in plant j within the municipal areas
Fk(k) - amount of MSW (organics) processed in the central processing plant k
Dist - distance
ColTrCost1 - collection and transportation cost in MYR per ton of wastes from sources i to plants at municipal areas respectively (ijM)
ColTrCost2 - collection and transportation cost in MYR per ton of wastes from sources i to the centralized processing plant k (ikL)
PlantCOST - plant cost (capital OM) of plants at each of the municipal areas and the central processing point in MYR
BgGenCost - biogas generation cost at the processing plants
BgAmnt - amount of biogas produced at the processing plants
electGenCOST - electricity production cost in MYR
electGenerated - Amount of electricity generated at plants

```
electSale -  electricity sale in MYR KWh

SETS
M index for MSW (organics) in municipal area /M1*M5/
*M1     Pasir Gudang (MPPG)
*M2     Kulai (MPKu)
*M3     Pontian (MDP)
*M4     Johor Bahru (MBJB)
*M5     Johor Bahru Tengah (MPJBT)

i  MSW (organics) generation sources in each municipal area /i1*i3/
*i1
*i2
*i3
j processing plant ppf situated in each of the municipal area /j1,j2,j3,j4,j5/
*j1
*j2
*j3
*j4
*j5
k centralized processing plant cpp /k/
*k
;
SCALAR
cfb MSW (organics) to biogas conversion factor at plants /0.45/
cfe biogas to electricity conversion factor at plants /0.75/

TABLE
Fi(i,M) MSW (organics) availability in kg at source i of each of the municipal area
        M1     M2     M3     M4     M5
i1      150    200    50     200    300
i2      200    300    200    100    400
i3      50     100    150    200    250

;

Parameter

UColTrCost1  Unit collection and transportation cost in MYR per ton of wastes from source
to the plants respectively
/10/

UColTrCost2  Unit collection and transportation cost in MYR per ton of wastes from source
to the plants respectively
/15/

*Dist1  Distances from source to plant at municipal areas respectively /
*        M1    M2    M3    M3    M5
*i1.j1    10    0     0     0     0
*i2.j1    15    0     0     0     0
*i3.j1    5     0     0     0     0
```

```
*i1.j2   0    20   0    0    0
*i2.j2   0    10   0    0    0
*i3.j2   0    15   0    0    0

*i1.j3   0    0    5   0    0
*i2.j3   0    0    10   0    0
*i3.j3   0    0    15   0    0

*i1.j4   0    0    0    20   0
*i2.j4   0    0    0    5   0
*i3.j4   0    0    0    15   0

*i1.j5   0    0    0    0    5
*i2.j5   0    0    0    0    10
*i3.j5   0    0    0    0    15/

*Dist2  Distances from source to plant at municipal areas respectively /
*        M1    M2    M3    M3    M5
*i1.k    40   0    0    0    0
*i2.k    20   0    0    0    0
*i3.k    25   0    0    0    0

*i1.k    0    20   0    0    0
*i2.k    0    10   0    0    0
*i3.k    0    30   0    0    0

*i1.k    0    0    20   0    0
*i2.k    0    0    15   0    0
*i3.k    0    0    35   0    0

*i1.k    0    0    0    20   0
*i2.k    0    0    0    25   0
*i3.k    0    0    0    15   0

*i1.k    0    0    0    0    30
*i2.k    0    0    0    0    10
*i3.k    0    0    0    0    20/

*UPlantCOST Unit plant cost (capital OM)of plants at each of the municipal areas and the
central processing point in MYR /40/
*j1      40
*j2      25
*j3      20
*j4      30
*j5      45
*k       15/

UPlantCOST Unit plant cost (capital OM)of plants at each of the municipal areas and the
central processing point in MYR /40/
UelectGenCOST  unit electricity production cost in MYR/3/
```

```
UelectSalePrice   unit electricity saling price in MYR KWh/5/
CAP (j) Capacities in tons of the processing plants
/
j1   100
j2   120
j3   300
j4   200000
j5   150
/

capk
/
1000/
;
POSITIVE VARIABLES

Fij(i,j,M) amount of MSW (organics) taken from the souces i to plant j within the municipal
areas
Fik(i,k,M)  amount of MSW (organics) taken from the souces i in all the five municipal areas
to the central processing plant j
Fj(j,M)   amount of MSW (organics) processed in plant j within the municipal areas
Fk(k)    amount of MSW (organics) processed in the central processing plant k
*Dist1
*Dist2
ColTrCost1   collection and transportation cost in USD per ton of wastes from sources i to
plants at municipal areas respectively (ijM)
ColTrCost2   collection and transportation cost in USD per ton of wastes from sources i to
the centralized processing plant k (ikL)
PlantCOST       plant cost (capital OM)of plants at each of the municipal areas and the
central processing point in Rm
BgGenCost  biogas generation cost at the processing plants
BgAmnt amount of biogas produced at the processing plants
electGenCOST  electricity production cost in Rm
electGenerated  Amount of electricity generated at plants
electSale  electricity sale in Rm KWh
;

VARIABLEs
TC total cost
;

EQUATIONS
obj
eqn2
eqn3
eqn4
eqn5
eqn6
eqn7
eqn8
eqn9
```

```
eqn10
eqn11
eqn12
eqn13
;

obj..  TC =e= ColTrCost1 + PlantCost + ColTrCost2 + electGenCost - electSale ;
eqn2(i,M).. Fi(i,M) =e= sum(j,Fij(i,j,M)) + sum(k,Fik(i,k,M));
eqn3(j,M)..Fj(j,M) =e= sum (i,Fij(i,j,M));
eqn4(k)..Fk(k) =e= sum ((i,M),Fik(i,k,M));
eqn5..  ColTrCost1 =e= sum((i,j,M),Fij(i,j,M)*UColTrCost1);
eqn6..  ColTrCost2 =e= sum((i,k,M),Fik(i,k,M)* UColTrCost2);
eqn7..  PlantCost =e= sum((j,M),Fj(j,M)*UPlantCOST) + sum (K,Fk(k)*UPlantCOST);
eqn8(M).. BgGenCost =e= sum ((j),Fj(j,M)*cfb*UelectGenCOST) +
sum((k),Fk(k)*cfb*UelectGenCOST);
eqn9(M)..BgAmnt =e= sum ((j),Fj(j,M)*cfb + sum ((k),Fk(K)*cfb));
eqn10.. electGenCost =e= BgAmnt*cfe*UelectGenCOST;
eqn11.. electGenerated =e= BgAmnt*cfe;
eqn12.. electSale =e= electGenerated*UelectSalePrice;
eqn13..sum ((i,M),Fi(i,M)) =l= sum (j, CAP(j)) + CAPk;
MODEL          BioElect /all/;
SOLVE          BioElect minimizing TC using lp;
*DISPLAY        TC.1;
```

MODEL STATISTICS

```
BLOCKS OF EQUATIONS         13     SINGLE EQUATIONS          58
BLOCKS OF VARIABLES         13     SINGLE VARIABLES         125
NON ZERO ELEMENTS          407

GENERATION TIME     =       0.015 SECONDS      4 MB  24.5.6 r55090 WEX-WEI
EXECUTION TIME      =       0.015 SECONDS      4 MB  24.5.6 r55090 WEX-WEI
GAMS 24.5.6  r55090 Released Nov 27, 2015 WEX-WEI x86 64bit/MS Windows 01/16/19
09:02:20 Page 5
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Solution Report     SOLVE BioElect Using LP From line 212
```

S O L V E   S U M M A R Y

```
   MODEL   BioElect           OBJECTIVE  TC
   TYPE    LP               DIRECTION  MINIMIZE
   SOLVER  CPLEX              FROM LINE  212

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      1 Optimal
**** OBJECTIVE VALUE          143611.2500
 RESOURCE USAGE, LIMIT          0.016      1000.000
 ITERATION COUNT, LIMIT        22    2000000000
```

LIST OF PUBLICATIONS

Indexed Journal

1. Anwar Johari, **Habib Alkali**, Haslenda Hashim, Saeed I. Ahmed, Ramli Mat (2014). Municipal Solid Waste Management and Potential Revenue from Recycling in Malaysia, Modern Applied Science; Vol. 8, No. 4; 2014. **(Indexed by SCOPUS)**

Indexed Conference Proceedings

1. Johari, A., **Alkali, H**., Hashim, H., Ramli, M. & Ahmed, S. 2012b. Recycling as a Viable Option for Municipal Solid Waste Management in Malaysia. Conference on Emerging Energy and Process Technology.

2. **Alkali, H**., Johari, A., Hashim, H., Oladokun, O. A., Nyakuma, B. B., Aliyu, B. A., Shatri, A. (2017). Optimal Distribution of Municipal Solid Wastes to existing. Facilities in Iskandar Malaysia. Conference on Emerging Energy and Process Technology.