UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF HEALTH, ENVIRONMENTAL AND ECONOMIC IMPACT FROM WASTE LANDFILLING AND SEGREGATION PRACTICE IN MALAYSIA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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June 2020

Chair : Sharifah Norkhadijah Syed Ismail, PhD
Faculty : Medicine and Health Sciences

Malaysians disposed of 80 to 90% of their waste in landfills. Health, environmental and economic problems are well known linked to landfills. Thus, Malaysia has implemented the waste segregation at source programme under Act 672 since 2015. Objective: To assess health, environmental, and economic impact from waste landfilling and segregation practice from 2014-2018 in eight (8) states in Malaysia. Methodology: The study areas covered the states under Act 672 (Kuala Lumpur, Putrajaya, Pahang, Perlis, Kedah, Negeri Sembilan, Malacca, and Johor). The available data of solid waste (tonnes) were obtained from the Solid Waste and Public Cleansing Corporation (SWCorp) and Alam Flora Sdn. Bhd. The mathematical models were used to analyse the data of landfilled and segregated domestic waste. Greenhouse gas (GHG) emissions were estimated using the Intergovernmental Panel on Climate Change (IPCC) methodology. Leachate volume and heavy metals were estimated using adopted mathematical models from the Ministry of Housing and Local Government (KPKT) and Emission Estimation Technique Manual. Gerard mathematical models 1998 were used to estimate the land area required for waste disposal in landfills. Non-methane volatile organic compound (NMVOC) emissions and health risks were analysed using the mathematical models of Air Pollutant Emission Factors and the United States Environmental Protection Agency (U.S EPA). Waste management cost and profits were calculated using the adopted equations form literature review and KPKT. Results: There was a significant difference in the volume of collected waste between the states (p-value <0.001) where the highest volume of collected waste was Johor (967 thousand tonnes per year (t/yr.)). The segregation rate was recorded at 0.06% only and 99.94% of domestic waste was dumped in the landfills. The landfilled domestic waste emitted about 109 thousand t/yr. of methane (CH_4), equivalent to 2.74 million (M) t/yr. of carbon dioxide (CO_2-eq). About 68.65 t/yr. of CH_4 (equivalent to 1.72k t/yr. of CO_2) were potentially avoided by the waste segregation activity. Waste landfilling generated 565k m^3/yr. of leachate in which

the segregated waste avoided 354 m^3/yr. of leachate production and heavy metals (5.32 $x10^{-3}$ to 7.09 $x10^{-4}$ kg yearly). About 32.08 ha/yr. of the land area were used for waste disposal in landfills. The waste segregation practice avoided the use of landfill area about 20.10 ha/yr. There was an acceptable health risk exposure to NMVOC with the value of Hazard Quotient (HQ) <1 and Lifetime Cancer Risk (LCR) <1.0E-04. Overall, the country spent 426 million MYR/yr. for landfilling practice in which 267 thousand MYR/yr. was saved by waste segregation practice. The country could generate the revenues from the electricity selling (43 thousand MYR/yr.) or carbon credits (176 million MYR/yr.) through landfill gas recovery and the selling of recyclable (530 thousand MYR/yr.). Conclusion: Segregation practice potentially reduced GHG emissions, leachate production, land use, health risks and waste management cost. It may generate high revenue through energy production, carbon credit and recyclable selling.

Keywords: Greenhouse gas, leachate, land use, health risk, profits

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sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN IMPAK KESIHATAN, PERSEKITARAN DAN EKONOMI DARIPADA AMALAN PENIMBUSAN SISA DAN PENGASINGAN SAMPAH DI MALAYSIA

Oleh

JOSFIRIN UDING ANAK RANGGA

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Rakyat Malaysia melupuskan 80 hingga 90% sisa pepejal di tapak pelupusan sampah. Masalah kesihatan, persekitaran, dan ekonomi adalah diketahui berkaitan rapat dengan tapak pelupusan. Oleh itu, Malaysia telah melaksanakan proram pengasingan sisa di punca di bawah Akta 672 semenjak tahun 2015. Objektif: Untuk menilai kesan kesihatan, persekitaran, dan ekonomi daripada penimbusan dan amalan pengasingan sisa dari 2014-2018 di lapan (8) negeri di Malaysia. Metodologi: Kawasan kajian hanya meliputi negeri-negeri di bawah Akta 672 (Kuala Lumpur, Putrajaya, Pahang, Perlis, Kedah, Negeri Sembilan, Melaka, dan Johor). Data sisa pepejal (tan) telah diperoleh daripada Perbadanan Pengurusan Sisa Pepejal dan Pembersihan Awam (PSPPA) dan Alam Flora Sdn. Bhd. Model matematik telah digunakan untuk menganalisis data sampah domestik yang dilupuskan dan diasingkan. Pelepasan gas rumah hijau (GRH) telah dianggarkan menggunakan metodologi *Intergovernmental Panel on Climate Change (IPCC)*. Isi padu dan logam berat dianggarkan menggunakan model matematik yang diadaptasi dari Kementerian Perumahan dan Kerajaan Tempatan (KPKT) dan *Emission Estimation Technique Manual*. Model matematik Gerard 1998 telah digunakan untuk menganggarkan keluasan tanah yang diperlukan untuk pembuangan sampah di tapak pelupusan. Pelepasan sebatian organik bukan metana (NMVOC) dan risiko kesihatan telah dianlisis menggunakan model matematik *Air Pollutant Emission Factors* dan Agensi Pelindungan Alam Sekitar Amerika Syarikat (U.S EPA). Kos pengurusan sampah dan keuntungan telah dianggarkan menggunakan persamaan yang diadaptasi daripada tinjauan literatur dan KPKT. Hasil kajian: Terdapat perbezaan yang signifikan bagi jumlah sampah yang dikumpulkan antara negeri (p-value <0.001) di mana jumlah tertinggi ialah Johor (967 ribu tan setahun (t/thn.)). Kadar pengasingan dicatatkan hanya 0.06% dan 99.94% sisa domestik dilupuskan di tapak pelupusan sampah. Sisa domestik menghasilkan kira-kira 109 ribu t/thn. metana (CH_4), bersamaan dengan 2.74 juta t/thn. karbon dioksida (CO2-eq) di tapak pelupusan. Lebih kurang 68.65 t/thn. CH_4 (bersamaan dengan

1.72 ribu t/thn. CO_2) berpotensi dielakkan oleh aktiviti pengasingan sampah. Pembuangan sisa pepejal menghasilkan 565 ribu m^3/thn. larut lesap di mana sisa yang diasingkan mengelakkan 354 m^3/thn. pengeluaran larut resap dan logam berat (5.32 x10-3 hingga 7.09 x10-4 kg setiap tahun). Lebih kurang 32.08 ha/thn. kawasan tanah digunakan untuk pembuangan sampah di tapak pelupusan. Amalan pengasingan sampah mengelakkan penggunaan tanah sebanyak 20.10 ha/thn. Tiada kesihatan yang berisiko terhadap pendedah kepada NMVOC dengan nilai darjah bahaya (HQ) <1 dan Risiko Kanser Sepanjang Hayat (LCR) <1.0E-04. Secara keseluruhannya, negara telah membelanjakan 426 juta MYR/thn. bagi amalan pelupusan sisa di tapak pelupusan sampah di mana 267 ribu MYR/thn. telah dijimatkan melalui amalan pengasingan. Negara boleh menjana pendapatan melalui penjualan elektrik (43 ribu MYR/thn.) atau karbon kredit (176 juta MYR/thn.) melalui pemulihan gas tapak pelupusan dan penjualan bahan kitar semula (530 ribu MYR/thn.). Kesimpulan: Amalan pengasingan sisa berpotensi mengurangkan pelepasan GRH, pengeluaran larut resap, penggunaan tanah, risiko kesihatan dan kos pengurusan sisa. Ia dapat menjana pendapatan yang tinggi melalui pengeluaran tenaga, karbon kredit dan penjualan bahan kitar semula.

Kata kunci: Gas rumah hijau, larut resap, penggunaan tanah, risiko kesihatan, keuntungan

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. Members of the Supervisory Committee were as follows:

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3R	Reduce, Reuse, And Recycling
ABC	Action Plan For A Beautiful And Clean Malaysia
ANOVA	Analysis Of Variance
ASEAN	Association Of Southeast Asian Nations
AT	Averaging Time
BW	Body Weight
C&D	Construction And Demolition Waste
CC	Collection Cost
CC	Carbon Credits
Cd	Cadmium
Ch	The Average Of Heavy Metals Concentration
CH_4	Methane
C*i*	Concentration Of NMVOC
CO_2	Carbon Dioxide
CO_2-eq	Carbon Dioxide Equivalent
C*P*	The Default Concentration Of NMVOC
CP	Collection Price
Cr	Chromium
Cu	Copper
DEWHA	Department Of The Environment, Water, Heritage And The Arts Of Australian Government
DG	Director General
DOC	Degradable Organic Carbon
DOCF	Degradable Organic Carbon Fraction
DOSM	Department Of Statistics Malaysia
EC	Energy Content

ED	Exposure Duration
EF	Exposure Frequency
EP	Electricity Production
EPA	Environmental Protection Authority
EU	European Union
F	Methane Fraction
FOD	First Order Decay Model
GDP	Gross Development Product (Gdp)
GGP	Government Green Procurement
GHG	Greenhouse Gas
GNI	Gross National Income
GWP	Global Warming Potential
H_2S	Hydrogen Sulfide
HDI	Human Development Index
Hg	Mercury
HHW	Households Hazardous Waste
HI	Hazard Index
HM	The Quantity Of Heavy Metals
HQ	Hazard Quotient
i	The Type Of NMVOC
IE	Inhalation Exposure
IPCC	Intergovernmental Panel On Climate Change
IR	Inhalation Rate
IRIS	Integrated Risk Information System
JHR	Johor
JPBD	Jabatan Perancangan Bandar Dan Desa
JPSPN	National Solid Waste Management Department

KDH	Kedah
KPKT	Ministry Of Housing And Local Government
KUL	Kuala Lumpur
LCA	Life Cycle Assessment
LCR	Lifetime Cancer Risk
LFG	Landfill Gas
LFGRS	Landfill Gas Recovery System
LFS	Landfill Space
LP	Land Price
LRT	Light Rail Transit Line
LTC	Leachate Treatment Cost
LUC	Land Use Cost
Mb	Methane Biogas
MLK	Malacca
MP	Malaysia Plan
MSW	Municipal Solid Waste
MSWF	Municipal Solid Waste Fraction
MSWT	Total Municipal Solid Waste
MYR	Malaysian Ringgit
NA	Not Available
NGO	Non-Governmental Organisation
Ni	Nickel
NMVOC	Non-Methane Volatile Organic Compounds
NSN	Negeri Sembilan
NSP	National Strategic Plan
OECD	Organization For Economic Co-Operation And Development
Pb	Lead

PHG	Pahang
PJY	Putrajaya
PLS	Perlis
PP	The Product Prices
PPP	Pay-Polluter Principle
PRISMA	The Preferred Reporting Items For Systematic Reviews And Meta-Analyses
RCM	Recyclable Materials
RCM	Recyclable Materials
RLA	Required Land Area
RM	Ringgit Malaysia
RP	Price Of Recyclable Material
RS	Recyclable Selling
SD	Standard Deviation
SDG	Sustainable Development Goals
SPSS	The Statistical Package For Social Sciences
SR	Segregation Rate
SWCorp	Solid Waste And Public Cleansing Corporation
SWML	Solid Waste Management Lab
SWPCM	Solid Waste And Public Cleansing Management
SWSR	Solid Waste Segregation and Recycling
TC	Transportation Cost
TF	Landfill Tipping Fee
TFP	The Price For Tipping Fee
TP	Transportation Price
U.S. EPA	United States Environmental Protection Agency
UK	United Kingdom

UNDP	United National Development Programme
US	United States
USD	United States Dollar
VHDI	Very High Human Development Index
VL	Volume Of Leachate
WTE	Waste To Energy
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 Background

Waste is “any discarded, rejected, abandoned, unwanted or surplus matter, whether or not intended for sale or recycling, reprocessing, recovery or purification by a separate operation from that which produced the matter” (Environment Protection Authority [EPA] 2009). It includes organics waste, paper, plastics, glass, metals, household hazardous waste (HHW), and others (i.e. diapers, rubber, textiles, leather) (National Solid Waste Management Department [JPSPN], 2013). They come from the households (65%), institutions and commercial (28%), and industries (7%) (Hoornweg & Perinaz, 2012).

At present, the global municipal solid waste (MSW) generation is at 1.3 billion tonnes per year (t/yr.) and expected to increase up to 2.2 billion t/yr. in 2025 with generation per capita increase from 1.2 to 1.4 kg/capita/day (Hoornweg & Perinaz, 2012). Malaysians generate 38,000 tonnes per day (t/day) of solid waste with an average of 1.17 kg/capita/day (Albakri 2016; Ministry of Housing and Local Government [KPKT], 2018). This is higher compared to other Asian countries such as Thailand (1.0 kg/capita/day), South Korea (0.99 kg/capita/day), Japan (0.98 kg/capita/day), Indonesia (0.70 kg/capita/day), China (0.63 kg/capita/day), and India (0.5 kg/capita/day) (Hoornweg & Perinaz (2012).

Landfilling is the preferable method for waste disposal by the country (Uyen & Schnitzer, 2009). This method also applied in other developing countries (e.g., China; India) due to its low cost of operation and maintenance (Dong et al., 2010; Vij, 2012). In Malaysia, the country operates 17 (11%) sanitary landfills and 141 (89%) non-sanitary landfills (JPSPN, 2018). The landfill is well known as a source of anthropogenic greenhouse gas (GHG) emissions that have a significant impact on the global warming potential (Yucekaya, 2014).

Exposure to landfills’ air pollutants (e.g., NMVOC) linked to human health problems such as cardiorespiratory failure, respiratory arrest, reproductive problem, mortality, and cancer (e.g., lung cancer, larynx cancer) (Giusti, 2009; Triassi et al., 2015; Cogut, 2016). People who are living near the landfill site having a high risks exposure to the pollutants through inhalation or ingestion (Giusti, 2009). Previous studies report that long term exposure to the NMVOC has the potential to cause carcinogenic and non-carcinogenic effects (Moolla, Valsamakis, Curtis, & Piketh, 2013; Yao et al., 2019).

Wastes in landfills produce leachate and heavy metals that will discharge into and pollute soil, surface, and groundwater (Suratman, Tawnie, & Sefei, 2011). Highly dependence on landfills will reduce its life expectancy that requires constructing a new landfill rapidly and increase the use of land to overcome space scarcity (KPKT, 2015). The typical operational costs in waste management include collection, transportation, landfill (disposal), and recycling cost (Greco, Allegrini, Del Lungo, Gori Savellini, & Gabellini, 2015). The annual growth rate of MSW in Malaysia is about 3 to 4%; which consume 40 to 80% of local authorities' expenditure on waste management (Nadzri, 2012).

Therefore, Malaysia's government has introduced some approaches to divert a considerable amount of waste from landfills in order to reduce its impact on the environment, health and economy. Waste segregation programme under Solid Waste and Public Cleansing Management Act (Act 672) is one of the strategies that has been implemented in Kuala Lumpur, Putrajaya, Pahang, Perlis, Kedah, Negeri Sembilan, Malacca, and Johor (KPKT, 2015). The programme aims to increase the recycling rates in the country and reduce the volume of waste in landfills (KPKT, 2015). The other states (Selangor, Penang, Perak, Terengganu, and Kelantan) not under Act 672 because they have decided not to privatise their solid waste management. Meanwhile, Sabah and Sarawak have their own regulations on waste management (Fatma, Latifah, Mariani, & Sabrina, 2018).

Moreover, MSW has a high organic content and calorific value that make it has the potential for energy production (Lee, Han, & Wang, 2017). According to Ham & Lee (2017), waste to energy approach positively contributes to the reduction of GHG emissions and avoid the impact on human health (Ham & Lee, 2017). Recycling also potentially reduces the amount of waste in landfills and its disposal costs (Denne, Irvine, Atreya, & Robinson, 2007). In addition, practising waste recycling provides high profits to a country and cost-effective than landfilling practice (New Jersey WasteWise Business Network, 2015).

1.2 Problem Statement

Waste generation in Malaysia had increased from 6.94 million t/yr. in 2005 to 13.94 million t/yr. in 2016 (Mohd Pauze, 2016). With the estimation of population growth of 33.34 million in 2020, the waste generation is expected to increase to 18.13 million t/yr. (KPKT, 2015). Malaysia disposed of a huge amount of waste in the landfills which is 80 to 90% (Uyen & Schnitzer, 2009). Malaysia recycling rate (17%) is low compared to other Asia countries such as Singapore (59%), South Korea (49%), and Japan (21%) but, higher than Thailand (11%), Indonesia (6), and the Philippines (5%). The top three of worldwide recycling rates are Austria (63%), Germany (62%), and Taiwan (60%) (JPSPN, 2013; The Statistics Portal, 2018).

According to the United Nations Development Programme (UNDP), the Human Development Index (HDI) is a summary measure of average achievement in key

dimensions of human development. The three key dimensions are a long and healthy life, knowledge, and a decent standard of living. In 2017, Malaysia's HDI was high (0.802) compared to other countries such as Thailand (0.755), China (0.751), Indonesia (0.694), and India (0.639) (United Nations Development Programme [UNDP], 2018). As the HDI value increased, Malaysia Gross National Income (GNI) per capita and Gross Development index (GDP) also increased (158.7%) (UNDP, 2018). A high waste generation in a region significantly correlated to the GDP (Kawai & Tasaki, 2016). For example, based on the study in European Union (EU), the waste generation was estimated to increase by 52% when the GDP increase by up to 67% from 2006-2030 (Sjöström & Östblom, 2010). Another study in Indonesia also reported that high waste generation in the cities (i.e., Jakarta, Surabaya) with high GDP and economic growth compared to the cities (i.e., Yogyakarta, Banda Aceh, Padang) with low GDP and economic growth (Rahardyan, Prajati, & Padmi, 2015).

A landfill is a source of anthropogenic greenhouse gases (GHG) that releases 50% methane (CH_4), 45% carbon dioxide (CO_2), and 5% other gases (i.e., nitrogen (N), oxygen (O_2), hydrogen sulfide (H_2S), and NMVOC (Tomonori et al., 2011; Yucekaya, 2014). Landfills contribute 5% of GHG to the total global GHG emission (Hoornweg & Perinaz, 2012). For example, according to the Synthesis Report 2014 by the Intergovernmental Panel on Climate Change (IPCC), GHG is a significant concern globally due to its potential to cause climate change and global warming (IPCC), 2014). The changes in climate are expected to increase the risk to people, assets, economies, and ecosystem due to heat stress, storms, extreme precipitation, inland, and coastal flooding, landslides, air pollution, drought, water scarcity, sea-level rise, food security, infrastructure, and agricultural incomes (IPCC, 2014).

Furthermore, disposal of residual waste (i.e., the mixed waste contains organic, inorganic, and electronic waste) in landfills produces leachate containing heavy metals (e.g., cadmium (Cd), copper (Cu), zinc (Zn), lead (Pb)). It has been proven in many studies, such as by Emenike, Fauziah, & Agamuthu (2012); Al-Raisi, Sulaiman, Suliman, & Abdallah (2014); Zairi, Aydi, & Dhia (2014); and Talalaj (2015). Leachate seeping over a landfill and carrying out these toxic elements into the soil and percolate into the groundwater. For example, previous studies have reported that heavy metals were detected in soil and groundwater near the landfill sites in Malaysia (Sharifah, Che, Mohd. Armi, Erneeza, & Aini, 2015; Mohd Raihan, Wan Zuhairi, Abd Rahim, & Jasni, 2011; Atta, Zuhairi, Yaacob, & Jaafar, 2015).

An increase in waste generation every year leads to a rise in the use of the land area for waste disposal and reduce landfills lifespan (Khajuria, Yamamoto, & Morioka, 2010). Rapid construction of new landfills to overcome the space scarcity for waste disposal will cause social, economic, and environmental impact. For example, it might reduce the available land for crop production that contributes to the country's economy (Wu, 2019). Deforestation or clearance of land area for the development of a landfill will alter the Earth's landscape and

destroys habitats or biodiversity that will lead to soil erosion, runoff, flooding, and landslide (Wu, 2019).

In terms of health impact, a study by Yu et al. (2018) highlights that exposure to landfill gas constituents impaired the lung function of nearby residents, especially among children. The NMVOC in landfills has the potential to cause carcinogenic and non-carcinogenic effects due to its level of toxicity (Moolla, Valsamakis, Curtis, & Piketh, 2013; Yao et al., 2019). The study by Moolla et al., (2013) reports that increasing of NMVOC emission in 2020 will increase the health risk (cancer and hazard risk) up to 98% among the landfill workers. Hydrogen sulfide (H_2S) was found the highest NMVOC emit in the landfill, which is around 57.9-49.1% (Wu et al., 2018; Cheng et al., 2019). Exposure to a high concentration of H_2S can cause respiratory problems, damage to the central nervous system, and permanent brain damage (Guo et al., 2019).

To date, the Malaysia government has spent approximately 5.24 billion USD every year for the management of solid waste in the country (Utusan Online, 2017). The cost of waste collection and disposal alone take up to 60% of local authority expenditure (Fauziah & Agamuthu, 2010). Besides, building up a new landfill in Malaysia requires more than 7.75 million USD (Zaipul & Ahmad, 2017). The current estimated cost for waste management in Malaysia, including collection, transportation, and disposal (landfill tipping fee), is about RM148/tonne/day (KPKT, 2015). Meanwhile, the cost of leachate treatment is RM 35/m^3 (KPKT, 2015).

In September 2015, the mandatory waste segregation programme was introduced under Act 672. The programme has been implemented in the federal states of Kuala Lumpur and Putrajaya and in six states in Peninsular Malaysia, which is Pahang, Perlis, Kedah, Negeri Sembilan, Malacca, and Johor. The households have to segregate their wastes into paper, plastic, miscellaneous, and non-recyclables accordingly (KPKT, 2019). Many of previous studies reported that 20 to 60% of waste segregation at source could reduce the potential impacts of global warming, environment, human health, and waste management cost (Kaazke, Meneses, Wilke, & Rotter, 2013; Eisted & Christensen, 2013; Maria & Micale, 2014; Coelho & Lange, 2018; Liikanen, Havukainen, Viana, & Horttanainen, 2018).

Since the implementation of mandatory waste segregation programme under Act 672, there are limited studies have been done to addresses the contributions of waste segregation and the impact of landfilling practice in Malaysia from the perspective of environmental, health, and economic impact. The latest studies on waste management in Malaysia by Sie et al. (2014) and Sie et al. (2015) only focused on the environment and economy where the health aspect was excluded in the analysis. Moreover, many of the past studies only highlighted the potential GHG emissions in landfills as renewable energy (Anwar, Saeed, Haslenda, Habib, & Mat, 2012; Alireza, Farzaneh, Jahanshaloo, Nor Azwadi, & Ali Esfandyari, 2016; Phun et al., 2017). Thus, the present study had performed the

health risk assessment (inhalation exposure) by analysing these aspects together (i.e., environment, health, and economy). Thus, it provides a clear comparison between the landfilling and segregation practices in terms of environmentally efficient, socially acceptable, and economically affordable.

Therefore, this study was designed to conduct a comprehensive assessment of the extent of waste landfilling and segregation rates in the country and how both practices impact the environment (i.e., GHG and NMVOC emission, leachate production, heavy metals, and land use), health (i.e., inhalation exposure to NMVOC), and economy (i.e., waste management costs, and profits through landfill gas recovery and recyclable selling). It in line with the National Solid Waste Management Policy 2016 (Trust 1) to encourage 3R activities (reduce, reuse, recycle), reduce waste generation, and to optimise the use of resources through waste segregation programme (JPSPN, 2016). The study also supports the Sustainable Development Goals (SDG) of the United Nations which including Good Health and Wellbeing (SDG 3), Clean Water and Sanitation (SDG 6), Decent Work and Economic growth (SDG 8), Sustainable Cities and Communities (SDG 11), Responsible Consumption and Production (SDG 12), and Climate Action (SDG 13).

On the other point of view, the study is expected to contribute to the knowledge of science through the scientific method of mathematical modelling that can be applied in waste management in more comprehensive ways. The new modeling of waste segregation rates based on the current data of segregated waste was developed in this study. It provides an overview of the government in decision-making and achieving a higher quality of waste management in the future. The model also can be used by the government in formulating a waste management policy, improving waste management strategies, and stimulating more research on waste management in Malaysia.

In this study, the focus study areas are the states who implemented Act 672 (Kuala Lumpur, Putrajaya, Pahang, Perlis, Kedah, Negeri Sembilan, Malacca, and Johor). Since waste segregation practice started in 2015, the data of segregated waste involved in this study was from 2015 to 2018. The available data of landfilled waste was from 2014 to 2018.

1.3 Study Justification

Limited research is found to describe the contributions of waste segregation in Malaysia. This study is important because it addresses the contribution of waste segregation to the reduction of landfill gas emissions and other environmental impacts (i.e., leachate, heavy metals, land use).

Many studies have estimated the emission of CH_4 and CO_2 in landfills. However, limited study, especially in Malaysia, that assessed the potential emission of

NMVOC and its impact on human health. Thus, this study highlighted the health risk assessment (non-carcinogenic and carcinogenic risk) of inhalation exposure to NMVOC among three groups (child, woman, and man). It shows that more research needs to be done in this field, especially for the future of waste management in the country.

Also, limited study has addressed the waste management cost for landfilling and its avoidance cost through waste segregation practice. The study also analyses the contributions of waste segregation practice in providing revenues through the selling of recyclable materials. Moreover, many previous studies also have reported that landfill gas recovery has the potential to reduce the GHG emission in landfills and provides revenues to the country by transforming waste into energy. A few studies have done in Malaysia on the estimation of energy and profits from landfill gas recovery. As Malaysia is actively planning on waste to energy (incineration) that might face many issues such as technical and environmental issues thus, this study focused on landfill gas recovery and highlighted the profits that could be gained by each of the states through landfill gas recovery and also selling of the recyclable materials.

Thus, this study could provide information to the government on the contributions of waste segregation, in which the baseline data will assist the government in planning effective waste management strategies in the country, especially on waste reduction and segregation. It also could attract other states (who do not implement Act 672) to adopt the Act and implement the mandatory waste segregation programme.

1.4 Conceptual Framework

Figure 1.1 illustrates the conceptual framework of the study. Rapid urbanisation, industrialisation, and population growth become major factors of the fast generation of solid waste quantities in worldwide (Hoornweg & Perinaz, 2012). Main municipal solid waste (MSW) come from households (65%) followed by commercials and institutions (28%) and industries (7%) (National Solid Waste Management Department [JPSPN], 2013). The main compositions include food waste (45%), plastics (13%), non-recyclables (12%); (i.e., diapers, sanitary towel etc.), paper (9%), garden (6%), and other wastes (16%); (glass, metal, leather, hazardous waste, etc.) (JPSPN, 2013).

The independent variable of the study is the volume of MSW (tonne) that categorised into two which are landfilled waste and segregated waste. The available data of segregated waste compositions include plastic, paper, metal, aluminium, glass, e-waste, and other wastes. The study selected the states under Act 672 (i.e., Kuala Lumpur, Putrajaya, Pahang, Perlis, Kedah, Negeri Sembilan, Malacca, and Johor) to compare the volume of waste by states and also by their human development index (HDI). According to the United Nations

Development Programme (UNDP), the HDI is a summary measure of average achievement in three key dimensions (i.e., long and healthy life, knowledge and a decent standard of living) in a region or country.

MSW management strategies can be consist of the pay-polluter principle, waste segregation and recycling, biological treatment (i.e., aerobic composting and anaerobic digestion), thermal treatment (i.e., incineration), and landfilling (i.e., with or without landfill gas recovery). In this study, we focus on studying the impact of landfilling and segregation practice.

The dependent variables of the study are environment, health, and economy. The study parameters for environmental impact is landfill gas emissions (i.e., methane (CH_4), carbon dioxide equivalent (CO_2) (tonne), and NMVOC (m^3)), leachate production, heavy metals, and land use. The health risks of carcinogenic (lifetime cancer risk, LCR) and non-carcinogenic (hazard index, HI) exposure (inhalation) to NMVOC were assessed among the three groups (i.e., child, woman, and man). The parameters for the economy (Malaysian Ringgit, MYR) are waste management costs (i.e., collection, transportation, disposal (landfill tipping fee), leachate treatment, and land use) and profits (i.e., landfill gas recovery and selling of the recyclable materials). These variables were analysed using the standardised mathematical equations.

The findings of the study are expected to promote and improve solid waste management in the country, provide baseline data to the government, and support stakeholders in decision-making. Besides, it will stimulate more research on solid waste management in the country in order to meet the 2016 National Solid Waste Management Policy under Trust 1. It focuses on the 3R activities (reduce, reuse, recycle) through the implementation of waste segregation program that aims to reduce the waste generation and to optimise the use of resources (JPSPN, 2016).

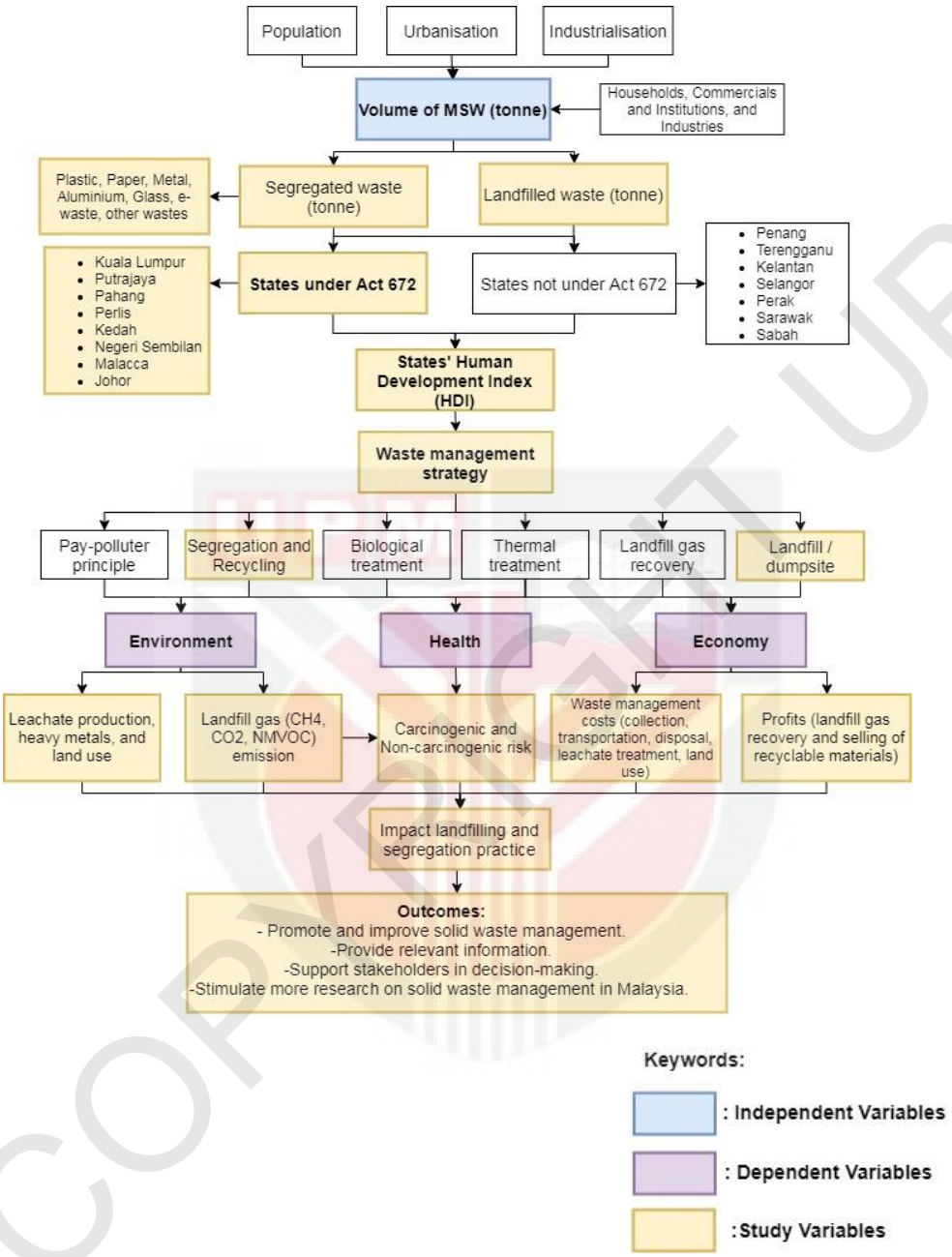

Figure 1. 1: The conceptual framework of the study

1.5 Research Questions

The study was designed to answer research questions as follows;

a) What is the extent of domestic waste landfilling and segregation rates in the country?

b) How landfilling and waste segregation practice impacts the environment and health?

c) How landfilling and waste segregation practice impact the economy?

1.6 Objectives

1.6.1 General Objective

To assess health, environmental, and economic impact from waste landfilling and segregation practice from 2014-2018 in eight (8) states in Malaysia.

1.6.2 Specific Objectives

1) To determine the total collected waste and its characteristics in the study area from 2014 to 2018.

2) To determine the volume of landfilled and segregated waste in the study area from 2014 to 2018.

3) To determine the waste segregation rates in the study area.

4) To compare the volume of landfilled and segregated waste between study areas and years.

5) To compare the volume segregated waste compositions between the study areas and years.

6) To assess the impact of waste landfilling and segregation practice on environment, health, and economy.

1.7 Hypothesis

1) There is a significant difference in the volume of landfilled and segregated waste between study areas and years.

2) There is a significant difference in the volume of segregated waste compositions between study areas and years.

1.8 The Scope of the Study

The scope of the study is the states implement waste segregation program under Act 672, includes Kuala Lumpur, Putrajaya, Pahang, Perlis, Kedah, Negeri Sembilan, Malacca, and Johor. The available data of solid waste (i.e., the volume of waste in tonnes) from 2014 to 2018 were obtained from the Solid Waste and Public Cleansing Corporation (SWCorp) and Alam Flora Sdn. Bhd. The volume of domestic waste (i.e., landfilled and segregated waste) were analysed using the standardised mathematical equations. The study focused on three main impacts, which are the environment, health, and economy. The environmental impact includes GHG emissions, leachate productions and heavy metals, and land use. The estimated emissions of NMVOC generated by landfilled waste were used to analyse the impact of landfill gas on human health. For the economic impact, the study analysed the cost of waste management for landfilling practice and the avoidance cost through segregation practice. The profits through landfill gas recovery and selling of the recyclable materials also emphasised in this study.

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