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Environmental Impacts of Construction and Demolition Waste Management Alternatives

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Construction and demolition waste (C&DW) arises mainly as by-products of rapid urbanisation activities. C&DW materials have high potential for recycling and reusing. Despite its potential, landfilling is still the most common disposal method. In Malaysia, C&DW practices are principally guided by economic incentives such as low disposal cost or inexpensive virgin material outweighing recycling cost resulting in low recycling rate. The purpose of this study is to access the environmental impacts caused by landfilling and the alternatives especially in assessing the damages to human health, ecosystems, and to the resources in the future 10 y. It aims to identify the better alternatives in reducing the environmental impacts of landfilling C&DW. Life cycle assessment (LCA) used in this study assessed the environmental impacts associated with all stages, from waste production to end-of-life of waste material. LCA can help to avoid the short-sighted, quick-fix landfilling as the main solution for C&DW by systematically compiling an inventory of energy, fuel, material inputs, and environmental outputs. The environmental impact of landfilling C&DW is estimated to increase 20.2 % if the business as usual (BaU) landfilling continues to the year 2025. Recycling will reduce 46.0 % of total damages and with the shorter travel distance, the environmental damage is further reduced by 82.3 %. Applying industrial building system (IBS) to reduce waste generation at-site reduced 98.1 % impacts as compared to landfilling scenario. The negative impacts derived from landfilling activity is significantly reduced by 99.5 % (scenario 8) through shifting to IBS, recycling, and shorter the travel distance from construction sites to material recycling facilities (MRF). The what-if scenarios illustrated the alternatives future circumstances, the inclusion of the uncertainty concept, and define the future path of C&DW industry outlook. The outcome of this study is informative and useful to policymakers, particularly in defining the way forward of C&DW industry in Malaysia.

1. Introduction

In developed countries, recycling of construction and demolition waste (C&DW) is regulated by law and policy such that the recycling rates have far surpassed 90 %. In Australia, almost 90 % of such waste was recycled (CCANZ, 2011), Japan's recycling rate is 99.5 % in 2012 (MLIT, 2014), and Singapore has demonstrated the highest recycling rate of 99.9 % (NEA, 2016). Malaysia's C&DW recovery rate remains at less than 50 % (UNCRD, 2015), a poor level attributed to a lack of institutional supporting policy, recycling programs, and recycling facilities in major cities. Notwithstanding legislation (Solid Waste and Public Cleansing Management Act 672) governing solid waste management in Malaysia (National Solid Waste Management Department, 2007), C&DW attracts significantly less attention than other forms of waste, such as municipal solid waste. In Lee et al. (2017) study, authors highlighted that sometimes C&DW is not listed as a waste category in landfill even though C&DW is disposed together in MSW landfill. C&DW, being both produced and managed mostly by the private sector, suffers from weak enforcement provisions. In Begum et al. (2009) study, cost, lack of knowledge and awareness of waste recovery are the major hindrances against source separation and recycling. Poon et al. (2001) study mentioned that the construction participants are reluctant to carry out on-site waste sorting even when a high tipping fee is imposed. Waste causes negative externalities to the environment, despite the fact that most of the C&DW are inert materials (Franklin Associates, 1998) and may not pose as great a threat as hazardous waste (Wang et al., 2004). Landfilling of C&DW depletes finite landfill

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resources (Marzouk and Azab, 2014), contributes to the increase of energy consumption, increases greenhouse gas (GHG) emissions, presents public health issues, and otherwise contaminates the environment. Waste industry in UK emits approximately 250.3 Mt CO_2 annually (BIS, 2010) and in the USA, it accounts for 39 % of the country's total CO_2 emissions (USGBC, 2006).

The C&DW management hierarchy (Figure 1) captures the progression of a waste material through the successive stages of waste management and represents the preferable end-of-life for the waste material life cycle. Waste management hierarchy aims to extract and utilise the material to the optimum scenario such as to maximise the economic value, to minimise the environmental impacts. Although source reduction is the top priority in the waste management hierarchy, it is always not easily attainable. Reuse of C&DW material can be achieved through building designs that support adaptation, disassembly, and reuse of the C&DW materials. Materials like soil, sand, gravel, and aggregate can be reused without reprocessing. Plywood for concrete casting is reusable up to a few cycles, depending of the wood material and after-use maintenance. At the end-of-life cycle, wood waste can be recycled into wood chip and utilised for bio-energy production. After reuse, recycling or down-cycling of C&DW material is the next preferred option. Most of the C&DW materials are potentially recyclable, should the right technology is applied.

Life cycle assessment (LCA) addresses the environmental aspects and potential environmental impacts throughout a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (ISO 14044, 2006). In waste management, LCA is a useful tool used in conducting a systematic environmental impacts assessment of different waste management scenarios. The LCA of a waste management scenario can differ from product LCA. Modelling waste disposal scenarios in life cycle assessment is an inverse version of the production model. Waste scenarios are the processes that refer to the material flows to end-of-life without observing the product characteristics. In waste scenarios, the information on waste material recycling processes are considered as subassemblies and the modelling of the subassemblies can be done through partial reuse or fully reuse operations. LCA of waste management might play a smaller role comparing to the whole product LCA, but due to the huge amount and bulky nature of C&DW, some components of C&DW like plasterboard are hazardous once landfilled. Such items can break down and release hydrogen sulphide, a toxic gas, in landfill.

In Bovea and Powell (2016) article, 71 (from 1999 – 2015) articles related to LCA in C&DW management were reviewed. Analysis shows that 66.3 % of the total articles are conducted and published in European countries such as Spain, Italy, Portugal, and Sweden, 15 % of the articles are from USA, and 10 % of the articles are from Asia, predominantly by China researchers. Bovea and Powell (2016) also highlighted that Asian countries have taken longer time to join in this research field. Of the 71 articles, none are from or concerning Malaysia. In Laurent et al. (2014) article, 222 (from 1995 – 2002) articles published in 5 major waste management journals were reviewed. Two out of the 222 articles that were reviewed were conducted in Malaysia, focusing on LCA of municipal solid waste. Despite the increasing amount of C&D waste in Malaysia, none of the research identified by both of the authors studied LCA in C&DW management. Laurent et al. (2014) suggested that more research is needed to focus on C&DW, which have been little assessed with LCA studies. Both of the authors, Pasqualino et al. (2008) and Ortiz et al. (2010) compared three scenarios in C&DW management: landfilling, incineration, and recycling. Pasqualino et al. (2008) concluded that incineration is the best solution for hazardous waste, and recommended recycling for other inert materials for a construction in Barcelona, Spain. In Ortiz et al. (2010) research, recycling is found to be the best option followed by incineration and lastly, landfilling of C&DW. Balasbaneh and Marsono (2010) conducted a LCA in assessing 2 types of construction material alternatives in industrial building system (IBS) frames (pre-cast concrete and prefabricated timber framing system). The study focused on the whole life cycle of IBS frames from extraction phase, use phase, maintenance phase, to end-of-life, waste treatment phase, and concluded that prefabrication of timber framing system possessed less environmental impact compared to the latter. Despite that study, there remains lack of clarity regarding the overall impact assessments, as the study boundary of both materials and the life cycle inventory analysis studies are not well described in the article.

The purpose of this study is to access the environmental impacts caused by different C&DW management scenarios especially in assessing the damages to human health, ecosystems, and resources in the future 10 years. It aims to identify the alternatives future in reducing the environmental impacts caused by landfilling of C&DW. This study is presented in 4 sections. Section 1 is the introduction and followed by methodology in section 2. Section 3 discusses the results and followed by sensitivity scenarios analysis in section 4.

2. Methodology

2.1 Life cycle assessment of waste management

There are four phases in LCA study: (i) the goal and scope definition, (ii) the life cycle inventory analysis (LCI), (iii) the life cycle impact assessment (LCIA), and (iv) the results interpretation according to the LCA - principles and framework (ISO 14040, 2006) and LCA - requirements and guidelines (ISO 14044, 2006). The study boundary focused on reduce, recycle, incineration with energy recovery, and landfill (Figure 1) scenarios. The ‘reuse’ scenario is not modelled due to the usage of construction and demolition waste materials vary greatly between projects that make it difficult to cut off the system boundary. The assessment excluded the embodied impacts from assemble, production, and use phases. C&DW materials consisted of 10 categories, brick, cement, concrete, gypsum, packaging, paper, and board, reinforced concrete, sand soil dirt, scrap metal, tiles, timber, and plywood. Packaging, paper, and board are disposed to municipal solid waste landfill instead of inert landfill.

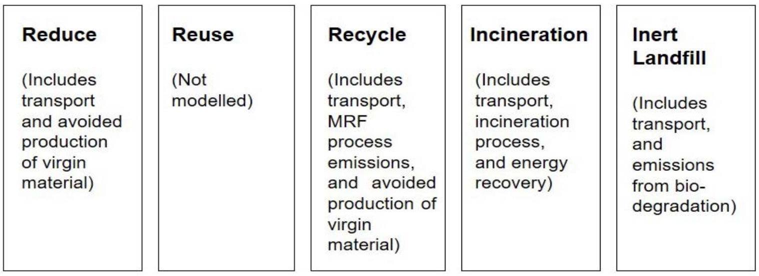

Figure 1: System boundary of mixed C&DW scenarios

The system boundary of the LCA study focused on waste management stage of C&DW material. The input data included in the life cycle inventory (LCI) are electricity usage in material recovery facility (MRF), fuel consumption, transport distances, and machineries used at the end of life of C&DW material. Life cycle inventories analysis of C&DW materials were modelled with Simapro software and Ecoinvent database with the functional unit of 1 t of C&DW reduce, recycle, incinerate, and landfilled. The environmental impact assessment was performed with endpoint indicators of Human health, ecosystems, and resources in MPt unit with the damage assessment method, ReCiPe.

2.2 Scenarios development and data collection

Scenario 1 (S1) and scenario 2 (S2) are the business as usual (BaU) waste flow. S1 is business as usual (BaU) in 2016 where all of the C&DW produced from construction site is dumped to the landfill. S2 is the estimation of BaU practice in 2025. The amount of waste generation in 2016 and 2025 are 1.8 Mt and 2.3 Mt (Table 1) (Mah and Fujiwara, 2017). Waste generated in 2025 was estimated with waste generation rate data from previous study, and statistical data published by the government.

Table 1: Input data for S1 and S2

Scenario setting	Unit	1. BaU 2016	2. BaU 2025
CS - LF	km	61	61
Total waste base year	t	1,847,446	2,339,613
LF machinery compactor	m^3	0.794	0.794
Total energy compactor	$t.m^3$	1,466,872	1,857,652
Transport lorry 16 - 32 t	t.km	112,509,431	142,482,451

3. Results and analysis

Table 2 shows the environmental impacts of 2016 and 2025 BaU scenarios and comparison of damage assessment for both scenarios.

Table 2: Environmental impacts of 2016 and 2025 business as usual scenarios

Environmental Impacts	Unit	1. BaU 2016	2. BaU 2025	Damage assessment in 2025 as compared to 2016 (%)
Human Health	(MPt)	1.99	2.40	20.6
Ecosystems	(MPt)	0.079	0.10	26.6
Resources	(MPt)	2.03	2.41	18.7
Total		4.10	4.91	20.2

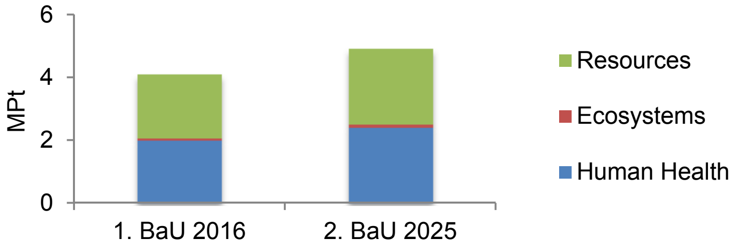

Figure 2: Comparison of damage assessment of scenario 1 and scenario 2 (Method: ReCiPe Endpoint (H) V1.12 / World ReCiPe H/A / Single score)

The damage assessment (Figure 2) shows that the damage assessment of S1- BaU will continues to rise 20.2 % at year 2025, without any counter-measure. The future of C&DW management is affected by many different variables such as policies development, construction technologies, waste generation and composition, and recycled materials acceptance rate. If the BaU practice continues to 2025, the human health damage is set to increases 20.6 %, ecosystems damage at 26.6 %, and damage to resources is at 18.7 % (Figure 2).

4. Sensitivity (what-if) analysis

Environmental performance of C&DW disposal scenario can be improved with better construction methods, for instance a shift to IBS construction method to reduce the waste generation on-site. Diversion of C&DW from entering landfill waste stream could possibly be a game changer too and three of these attributes were evaluated in the what-if scenarios:

- maximum diversion of C&DW away from landfill into material recovery facilities (MRF) for recycling,
- a mobile MRF is build at a minimal distance away from the center of C&DW generation source, and
- shift from conventional construction method to IBS construction method to reduce waste generation on-site.

Six what-if scenarios are depicted in Table 3 and damage assessment for of eight what-if scenarios are given in Figure 3 and Table 4.

Table 3: What-if scenarios base input data

Scenario setting		S3. Bau 50 % div 2025	S4. MaxDiv 2025	S5. MaxDiv MinDist 2025	S6. BaU IBS 2025	S7. IBS MaxDiv 2025	S8. IBS maxdiv mindist 2025
CS - LF	km	61			61		
CS - MRF	km	36.1	36.1		36.1	36.1	
CS - MRF MinDis	km			3			3
Total waste base year	t	2,339,613	2,339,613	2,339,613	367,045	367,045	367,045
LF machinery compactor	m^3	0.794			0.794		
MRF machinery energy	kWh/t	3.11	3.11	3.11		3.11	3.11
Total energy compactor	$t.m^3$	928,826			298,407		
MRF machinery energy	kWh	3,633,712	7,267,424	7,267,424		1,140,132	1,140,132
Transport lorry 16 - 32 t	t.km	113,471,246	84,460,041	7,018,840	22,353,016	13,250,310	1,101,134

S3 - S8 are designed as the counter-measure scenarios to the BaU scenarios (S1 and S2). S3 describes the C&DW materials that are separate into 2 categories: recyclable and non-recyclable. Recyclable materials are sent to MRF for separation and recycling. Non-recyclables are sent to landfill. S4 depicts the maximum diversion of C&DW away from landfill into recycling stream. S5 describes the maximum diversion of C&DW into recycling stream and the distance between CS to MRF is assumes to be at minimal, 3 km. S6 is the shifting of construction method from the conventional construction method to IBS method, reducing the total waste generation. S6 assumes BaU, landfilling of the reduced waste generation. Total waste generation for IBS method is estimated at 367,045 t (from previous study). S7 describes the combination of IBS method and maximum diversion into MRF for recycling. S8 describes the combination of S7 with minimal distance to MRF. The minimal distance is assuming within the radius of 3 km from CS (Table 3).

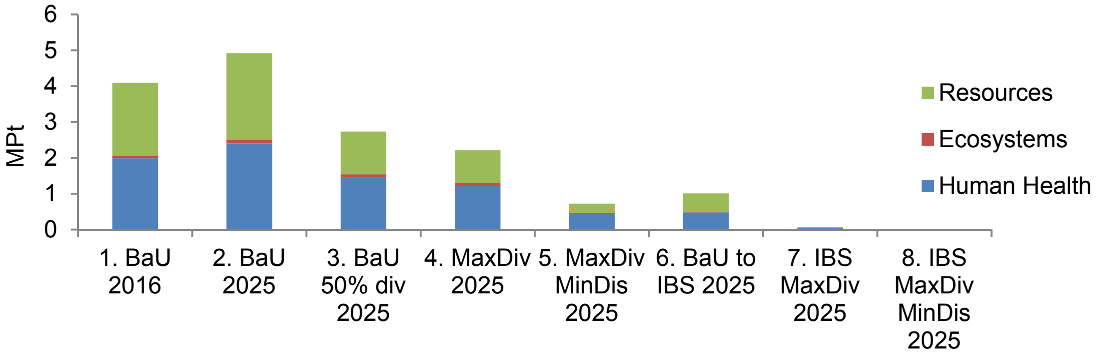

Figure 3: Damage assessment of what-if scenarios (Method: ReCiPe Endpoint (H) V1.12 / World ReCiPe H/A / Single score)

Table 4: Damage assessment of what-if scenarios

What-if scenarios (MPt)	Human Health	Ecosystems	Resources	Total	Compared to S1
S1. BaU 2016	1.987	0.079	2.025	4.092	
S2. BaU 2025	2.402	0.101	2.413	4.917	-20.2 %
S3. BaU 50% div 2025	1.448	0.091	1.192	2.732	33.2 %
S4. MaxDiv 2025	1.216	0.08	0.914	2.21	46.0 %
S5. MaxDiv MinDis 2025	0.431	0.024	0.27	0.726	82.3 %
S6. BaU to IBS 2025	0.479	0.015	0.515	1.009	75.3 %
S7. IBS MaxDiv 2025	0.043	0.003	0.032	0.077	98.1 %
S8. IBS MaxDiv MinDis 2025	0.011	0.0005	0.011	0.022	99.5 %

5. Conclusion

The environmental impacts caused by landfilling of construction and demolition waste is estimated to increases 20.2 % by 2025 if the business as usual (BaU) landfilling continues to year 2025. If 50 % of recycling rate can be achieved in 2025, the environmental impacts will reduce 33.2 % and it further reduce 46.0 % if 100 % of recycling. With maximum recycling and minimum distance to MRF, the environmental damages are reduced by 82.3 %. Reduction of travel distance to MRF means a great saving in damages. Reduction of the total waste generation accompanying a shift in construction method to industrialised building system (IBS) could further reduce the environmental damages at 75.3 %. With the combination of IBS to reduce waste generation at-site and maximum recycling of excess C&DW, it achieved a reduction of 98.1 % of environmental damages. The negative impacts derived from landfilling activity could be significantly reduced through shifting of current construction method to IBS construction method, reusing, recycling, and lastly reducing the travel distances between construction sites to material recovery facility (MRF). The optimal scenario is presented in waste disposal S8. Lowest environmental damages and the most environmental friendly scenario that reduce overall 99.5 % environmental impact in 2025 (Table 4).

What-if scenarios illustrate the alternatives future circumstances, the inclusion of the uncertainty concept, and define the path from present to the future outlook of construction and demolition waste industry. The outcome of this study can be informative and useful to policymakers, in particular of knowing which alternative to address the environmental hazard waste management scenario.

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