Barriers and critical success factors towards sustainable hazardous waste management in electronic industries – A review

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Abstract. This study reviews existing literature to determine the barriers and critical success factors (CSFs) towards sustainable hazardous waste management in electronic industries. Sustainable hazardous waste management can considerably reduce the volume of wastes going to landfill sites and can therefore reduce the burden to the environment in terms of pollution prevention and greenhouse gaseous reduction. This goal is achievable through efforts, such as waste recovery, waste-to-energy technology and waste-to-raw material conversion. Hazardous waste in Malaysia mainly comes from recovery facilities, metal refinery, metal finishing and coating, cement manufacturing, petroleum refinery and chemical, electrical and electronic industry. The electrical and electronic industry is a major contributor of hazardous waste generated in Malaysia. Some hazardous wastes, such as heavy metal sludge, generated by electrical and electronic industries can be utilised as alternative fuel for cement industries. The residue produced subsequently can be utilised as raw material for cement manufacturing. Despite the economic and environmental benefits of sustainable hazardous waste management efforts amongst industries, they remain relatively weak. The identified barriers include (1) complexity of legal requirements, (2) lack of systems and tools, (3) hazardous waste quantity and quality, (4) lack of awareness about environmental and sustainability issues, (5) poor partnership/networking, (6) public resistance, (7) financial constraints, (8) lack of information and (9) insufficient environmental resources. Nevertheless, the benefits gained from adopting sustainable hazardous waste management will continuously encourage an increasing number of organisations to devote efforts onto it. The success of this initiative depends on a few critical factors, including (1) readiness of hazardous waste beneficiary, (2) economic and environmental benefits, (3) stakeholders’ pressure, (4) adoption of ISO14001, (5) effects on corporate image, (6) commitment from the top management and (7) incentives and reward.

1. Introduction
Hazardous waste, also known as scheduled waste in Malaysia, is any waste that possesses hazardous characteristics and can adversely affect the public health and the environment. First Schedule of Environmental Quality (Scheduled Wastes) Regulations in 2005 listed 77 types of scheduled wastes and introduced provisions for the management of wastes. Regulation 7 of Environmental Quality (Scheduled Wastes) Regulations in 2005 allows hazardous waste producers to manage their respective hazardous wastes sustainably by converting the hazardous waste into energy or raw materials for other interested
parties. However, sustainable hazardous waste management efforts amongst industries remain relatively weak.

Malaysia is one of the 12 mega biodiversity countries in the world. However, the environmental performance of the country has worsened in recent years. Malaysia ranks 63rd in 2016 compared with 51st in 2014 in environmental performance index [1]. By contrast, its neighbouring country the Philippines has improved 48 ranks in the same period [2].

Hazardous waste in Malaysia mainly comes from recovery facilities, metal refinery, metal finishing and coating, cement manufacturing, petroleum refinery and chemical, electrical and electronic industry [3]. Amongst these industries, the scheduled waste generated from the electrical and electronic industry contains sludge composed of chromium, nickel, copper, lead, zinc, cadmium, tin, aluminium, beryllium and vanadium, which are categorised under code SW204 in the First Schedule of the Environment Quality (Scheduled Waste) Regulation in 2005.

The statistics published by Department of Environment (DOE) Malaysia (Table 1) showed that the total scheduled wastes generated in Malaysia in 2017 was approximately 2,017,281 metric tons (MT), of which 226,748 MT (11.24%) was SW204 (sludge containing heavy metals). SW204 is the third highest scheduled waste generated by various industries.

| Name of Waste                      | Waste Code | MT/Year    | Percentage (%) |
|------------------------------------|------------|------------|----------------|
| Dross/slag/clinker/ash             | SW 104     | 706,750.00 | 35.03          |
| Gypsum                             | SW 205     | 510,724.45 | 25.32          |
| Heavy metal sludge                 | SW 204     | 226,747.90 | 11.24          |
| Spend lubricating oil              | SW 305     | 94,528.12  | 4.69           |
| Spent acid                         | SW 206     | 86,664.98  | 4.30           |
| Contaminated container             | SW 409     | 47,509.28  | 2.36           |
| Mixture of scheduled waste and non- | SW 422     | 31,962.60  | 1.58           |
| scheduled waste                    |            |            |                |
| E-waste                            | SW 110     | 28,604.15  | 1.42           |
| Pathogen clinical waste            | SW 404     | 28,375.24  | 1.41           |
| Others                             | -          | 255,360.04 | 12.65          |
| **TOTAL**                          |            | **2,017,280.76** | 100   |

Source: [4]

One of the major generators of SW204 is the electrical and electronic industry (Table 2). SW204 is the heavy metal sludge produced from industrial wastewater treatment plants. These amounts of sludge are potential solid fuel (coal substitute) for cement industries and other energy generation facilities, such as power plants and steam boilers.

| Type of Industry                      | Quantity of Waste (MT/Year) | Percentage (%) |
|--------------------------------------|-----------------------------|----------------|
| Scheduled Waste Treatment and Disposal Facilities | 510,724.45 | 25.32 |
| Power Plant                          | 363,087.02                  | 18.00          |
| Chemical Industry                    | 276,242.51                  | 13.69          |
| Electrical and Electronic Industry   | 223,897.54                  | 11.10          |
| Metal Refinery                       | 166,618.59                  | 8.26           |
| Workshops                            | 63,094.96                   | 3.13           |
| Others                               | 116,294.88                  | 20.50          |
| **TOTAL**                            | **2,766,613.45**            | **100.00**     |

Source: [4]
However, out of 226,748 MT of SW204 generated, only 30,516 MT (7.43%) was reused as raw material for product manufacturing through special management under Regulation 7 of Environmental Quality (Scheduled Wastes) Regulations in 2005 (Table 3). By contrast, the remaining 196,232 MT (92.57%) of SW204 eventually ended up in sanitary landfill sites and thus had no economic benefit and added burden to the environment.

**Table 3. Special management of scheduled waste under Regulation 7 [4]**

| Waste Code | Source | Metric Ton | %  | Special Management Method                      |
|------------|--------|------------|----|------------------------------------------------|
| SW 104     | Power Plant | 363,087.02 | 71.16 | Reuse as raw material for product manufacturing |
| SW 104     | Industry  | 18,515.50  | 3.63 | Reuse as raw material for product manufacturing |
| SW 204     | Drinking water treatment plant | 26,032.33 | 5.10 | Sanitary landfill |
| SW 204     | Industry  | 63,822.59  | 12.51 | Sanitary landfill |
| SW 204     | Industry  | 30,515.88  | 5.98 | Reuse as raw material for product manufacturing |
| SW 406     | Industry  | 4,824.78   | 0.95 | Sanitary landfill |
| SW 427     | Industry  | 1,954.05   | 0.38 | Reuse as neutralisation agent |
| SW 320, 325, 418 | Industry | 885.78   | 0.17 | Sanitary landfill |
| SW 421     | Industry  | 501.35     | 0.10 | Reuse as raw material for product manufacturing |
| SW 409     | Industry  | 23.40      | 0.00 | Reuse as raw material for product manufacturing |
| SW 431     | Industry  | 10.39      | 0.00 | Slow burning method |
| SW 405, 429 | Industry | 10.00      | 0.00 | Sanitary landfill |

Source: [4]

The figures indicate that electrical and electronic industries can reduce the amount of hazardous waste going to landfill sites through sustainable waste management efforts. Rather than sending the scheduled wastes to landfills, which incurs a large cost, the heavy metal sludge generated from electronic industries can be used as alternative solid fuel for cement industries due to its high calorific value [5]. The fuels extracted from hazardous waste or the thermal use of solid recovered fuels in the clinker can eliminate the hazardous waste without producing any harmful gaseous by-products in the incinerator whilst providing cost savings for electronic and cement industries. Moreover, the residue left after the incineration of scheduled waste can be recycled as additive material to improve cement properties, such as reduced permeability, high resistance to sulphates and harsh environment condition, enhanced workability, or high-quality finish [3].

**Table 4. Approximate calorific value of materials**

| Type of Material                        | CV (MJ/kg) | CV (kCal/kg) |
|----------------------------------------|------------|--------------|
| Industrial and hazardous waste         | 22–40      | 5257–9558    |
| Medical waste                          | 19–24      | 4540–5735    |
| Domestic waste (without recycling)     | 7–16       | 1673–3823    |
| Domestic waste (after recycling)       | 10–14      | 2389–3345    |

Source: [6]
This paper provides an overview of common barriers and critical success factors (CFSs) towards sustainable hazardous waste management in electronic industries. The outcome of this literature review is expected to inform the scheduled waste generator and the energy producer or user about alternative ways of managing the scheduled waste in a sustainable and cost-effective manner through waste recovery and waste-to-energy efforts.

2. Methods
This study aims to identify the barriers and critical success factors (CSFs) that influence sustainable hazardous waste management efforts amongst electronic industries. Data and information were extracted from secondary data resources, such as government agency statistical reports, environmental reports and journal publications.

3. Importance of Sustainable Hazardous Waste Management
Global environmental problems, such as climate change, pollution and depletion of natural resources, have adversely affected human health and caused diseases. Sustainable hazardous waste management has become an essential global agenda that leads to the emergence of environmental protection legislations related to the control of hazardous substances and wastes. The awareness of consumers about the environmental impact resulting from their respective demand has motivated voluntary efforts to reduce the ecological footprint [7] and has therefore created new market opportunities for manufacturers of green products. Furthermore, the emergence of highly stringent requirements penalising the environmentally harmful behaviours manufacturers and the proactive governance of Non-Governmental Organizations (NGOs) have motivated manufacturers to better control their activities to reduce reputation risk and prevent additional cost.

To date, very limited studies have been conducted on sustainable hazardous waste management in Malaysia. Investigating the potential barriers to sustainable hazardous waste management in Malaysia is important due to the drastic increase in manufacturing activities and hazardous wastes. The barriers to sustainable hazardous waste management should be addressed immediately to tackle the environmental issues at present [8].

The impact caused by mishandling of hazardous waste, even in small amounts, is sometimes intolerable for some small countries with fragile environment by nature [9]. Many developed countries now have effective hazardous waste management systems in place. By contrast, countries with a long-term industrial base, such as China [10] and India [11], have not yet developed their hazardous waste management systems to the same extent.

Hazardous waste, which has toxicity, ignitability, corrosivity and reactivity, must be managed carefully to avoid unintentional release to the environment, which can lead to adverse effects to humans and biodiversity. Thus, the Ninth Malaysia Plan empowered the relevant agencies in adopting the global harmonised system to monitor the movements and safe handling of hazardous waste. In addition, the utilisation of technologies to treat and convert hazardous waste into a resource for reuse will be facilitated and implemented [12]. DOE Malaysia is also aggressively promoting a shift from ‘cradle-to-grave’ approach, in which wastes are treated as unwanted by-products, to ‘cradle-to-cradle’ approach, in which hazardous wastes are regarded as alternative resources and potential for energy recovery [3].

4. Barriers to Sustainable Hazardous Waste Management
‘Sustainability is a difficult term to be fully understood by many [13]. Sustainable hazardous waste management is achievable through waste recovery and waste-to-energy efforts that promote efficient use of energy and natural resources, reduce volume of waste generated and prevent pollution. However, the adoption of sustainable hazardous waste management remains subject to some barriers.

4.1. Complexity of legal requirements
DOE Malaysia encourages sustainable scheduled waste management under the provision of Regulation 7 of Environmental Quality (Scheduled Wastes) Regulations in 2005. However, the extensive evaluation
on the characteristic of the hazardous waste requires various testing on the waste and can thus be a potential factor discouraging the industry to proceed.

4.2. Lack of systems and tools
The availability of systems and tools is a crucial element of hazardous waste management because utilisation or disposal of the wastes is unattainable within the precondition for a long period. The management issues become increasingly complex because the waste has heterogeneous characteristics in terms of bioavailability, chemistry and toxicity. Thus, these hazardous wastes require special collection, treatment and recycling [14]. Li et al. [15] reported that incineration is the main refuse treatment in most cities in China with the aim to reduce waste volume, create less harm to humans and the environment and recycle the energy. However, recovering energy through incineration only works when the calorific value of the waste reaches a target value.

4.3. Hazardous waste quantity and quality
One of the potential beneficiaries of hazardous waste is the cement industry. A huge cement plant produces several thousand tons of clinker per day. Therefore, the demand for energy is high and must be met continuously. To cater to such demand, not only standard fuels, such as coal, fuel oil or natural gas, but also alternative fuels (solid hazardous wastes) must be available on site in sufficient quantity at any time [16]. The procurement of alternative fuels, including solid hazardous wastes, must fulfil several critical criteria, such as fuel properties (meet the specification required by the cement plant), availability (consistent quantity), price (cheaper than existing fuels used), process compatibility (will not damage the kiln), cement compatibility (no effect on cement quality), environmental compatibility (comply to emission limit) and approvability (comply to hazardous substance limit).

4.4. Lack of awareness about environmental and sustainability issues
One of the critical barriers for implementation of sustainable hazardous waste management is the lack of awareness about the environmental and sustainability issue. According to Siebenhuner and Arnold [17], for a company to become more sustainability orientated, it should make changes that include the introduction of resource-efficient technologies, sustainability reporting schemes and by providing sustainable products, services and product-service combinations.’

4.5. Poor partnership/networking
Statistical analysis done by Gunawardana [18] showed that most hazardous industries in Sri Lanka do not have proper integration amongst the parties that are responsible in hazardous waste management processes. This situation may be due to that the hazardous management area does not acquire sufficient concern and lack awareness on the importance of correct handling of hazardous waste. Moreover, some hazardous industries can have insufficient support and cooperation from hazardous waste management parties. Gunawardana [18] argued that many countries’ hazardous waste transport organisations and agencies of law enforcement are cold and detached towards hazardous waste management; this situation leads to restriction in this matter. Finding external partners to invest in sustainable hazardous waste technologies is difficult [8].

4.6. Public resistance towards hazardous industries
Van der Sloot and Kosson [19] pointed out that national awareness of liquid and solid hazardous waste issues grew exponentially in the middle of 1970s with extensive concern over mishandled waste, miscellaneous dumping of liquid waste and rare but visible transportation accidents. In Sir Lanka, some hazardous industries have been forced to close down because of harsh public resistance. Gunawardana [18] found that most industries generating hazardous waste have dealt with public resistance because of inappropriate management of hazardous waste.
4.7. Financial constraints
The success of sustainable hazardous waste management depends on the amount of investment spent on it. Various waste reduction projects change the standard production progression to assist recovery of hazardous waste material and involve high cost [18]. Thus, the lack of adequate finance for supporting eco-efficiency initiatives acts as a barrier.

4.8. Lack of information
The lack of technology information and market availability will prevent a company from adopting sustainable practices because the market demand is uncertain [8]. Sustainable hazardous waste management is a newer subject than other environmental management parameters. Information is an essential point for the electronic industry that applies modern technologies, and local and international information are necessary to investigate various compositions of hazardous waste. With the correct information, various kinds of hazardous waste can be identified efficiently and contribute massively towards successful hazardous waste management practices. Hazardous waste is always produced as a part of a structure. Therefore, identification of waste with the reference of updated information is important [18].

4.9. Insufficient environmental resources
Environmental management knowledge is essential to provide environmental management skilled personnel in the particular field for constructing a sustainable organisation. Lack of expertise in this area leads to less effort in sustainable hazardous waste management. Furthermore, findings showed that trained employees do not prefer to stay long in an organisation to assist in sustainable management [8]. The organisation that focuses on short-term tasks has low emphasis on long-term sustainable management practices [20]. This situation will further obstruct the adoption of these practices because the related works will bring burden for other employees and result in low success rate. Insufficient qualified staff can be a critical constraint to the development of sustainable hazardous waste management in an organisation.

5. Critical Success Factors of Sustainable Hazardous Waste Management
The amount of electronic wastes (e-wastes) disposed in 2017 was approximately 28,604 MT. E-waste may contain hazardous substances, such as heavy metals, carcinogens and ozone depleting substances, that are risky to human health and the environment; nevertheless, it contains precious materials that can be recovered as secondary resources for reuse and can thus minimize the exploitation of natural resources and reduce greenhouse gas emissions [21]. In Malaysia, 146 e-waste recovery facilities have the total capacity to handle more than 24,000 MT of e-waste per month. Amongst the 146 e-waste recovery facilities, 128 are partial recovery facilities engaged in physical or manual segregation of e-wastes for further processing; on the contrary, the remaining 18 are full recovery facilities that can process e-wastes to recover precious metals [4].

5.1. Readiness of hazardous waste beneficiary
Manufacturing of cement consumes a large portion of raw material and energy including heat and electricity. The process uses approximately 3.2 GJ to 6.3 GJ of energy and 1.7 t of raw materials in cement production. This energy intensive industry can spend thermal energy of up to 20%–25% of the production cost and consume 110–120 kWh of electrical energy per ton of cement [3]. Thomanetz [5] indicated that hazardous waste can be used as alternative fuels in cement plants, but the waste must first be processed in a special preconditioning plant. Alternative fuels made from several liquids and pasty and solid hazardous wastes can yield up to 120 000 t/year. A fine conveyable calorific fuel is created by blending the waste with saw dust. Converting the hazardous waste into cement fuels can save the conventional fuel and raw material whilst preventing landfiling and underground storage of waste. The mineral residues from the process are embedded within the clinker rather than dumped as waste.
Operational cost can be decreased because this process has lower price than the conventional incineration of hazardous waste.

5.2. Economic and environmental benefits
Reduction in cost and environmental load is achievable through an appropriate management of waste incineration with decreased primary energy consumption [22]. Anett Zajáros et al. [23] showed that solvent recovery in manufacturing technology of EVOH-based adsorbent can reduce the amount of hazardous waste water from 265.2 t/year to 5.5 t/year (98% reduction).

Alternative fuels as thermal recycling use industrial wastes, such as waste oils, plastics, auto shredded residues and waste tyres, and clay substitutes as material recycling use sewage sludge and industrial wastewater treatment sludge with alumina and silica [24-25]. Turning hazardous waste into raw material or energy (solid fuel) has the following benefits towards the environment, public health and economy:
- High temperature with long residence time and intensive turbulence within the rotary kiln can destroy most of the hazardous organic matter.
- Mineral residues will be embedded within the clinker and become part of the product; no waste will be disposed.
- Reduce the usage of conventional fuel (such as coal, fuel oil or natural gas).
- Reduce the amount of waste going to landfill and underground storage.
- Reduce the cost of sending waste to conventional hazardous waste incineration.
- Reduce the rate of natural resource depletion (coal and petroleum).
- Reduce potential health and environmental impact caused by hazardous waste.

5.3. Stakeholders’ pressure
Stakeholders refer to the individuals and groups of people who can influence the performance of the company or who are influenced by the actions of the company [26]. Environmental consciousness of a company indicates harmonising environmental performance with the expectations of stakeholders [27]. Thus, the performance of the company is affected by the pressures of its perception from stakeholders and importance for the progress of proactive environmental strategies. Stakeholders can motivate the acts of proactive environmental strategies. For example, the development of relationship with stakeholders and even the probability of affecting some of them are advantages contributing to environmental proactivity [28].

5.4. Adoption of ISO14001
As stipulated under Clause 6.1.1 of ISO 14001:2015, an organization shall determine the environmental aspects of its activities, products and services under its control and influence and their associated environmental impacts from a life cycle perspective. Such requirement intends to reduce the generation of waste by adopting ‘cradle-to-cradle’ approach that requires sustainable waste management strategies for its success. Therefore, adopting ISO14001 will directly motivate an organisation to make much effort in managing their waste sustainably. Quazi et al. [29] argued that the top management of companies that have been practising ISO14001 standard will eventually be more concerned on the natural environment than other companies that have not.

5.5. Effects on corporate image
The environmental effort of large companies can imply positive effect on many customers [28]. King and Lenox figured that large organisations have higher success rate of probability in adopting the ISO 14001 standard than their small counterparts.

5.6. Commitment from the top management
Del Brio et al. observed that the organisation has high attention on sustainable environmental practices when the involvement of the top management and their understanding of the benefits, disadvantages and tools of the environmental management is high. Priorities of the top management strongly influence the
organisational culture with respect to environment management, corporate responsibility and sustainability management [30]

5.7. Incentives and reward
Incentives and reward can stimulate great efforts in some cases. Such initiatives make people feel that their extra efforts are being appreciated and thus motivate them to progress further. Thus, the Malaysia government provides incentives in the form of investment tax allowance for the purchase of green technology assets and income tax exemption for the use of green technology services and systems. Incentives are also offered for establishing waste ecological parks.

6. Conclusions
The increasing generation of hazardous waste calls the need for action in hazardous waste management. Sustainable hazardous waste management can considerably reduce the volume of wastes going to landfill sites and can therefore reduce the burden to the environment in terms of pollution prevention and greenhouse gaseous reduction. Adopting these strategies has many barriers, such as complexity of legal requirements, lack of systems and tools, waste quantity and quality, lack of awareness about environmental and sustainability issues, poor partnership/networking, public resistance, financial constraints, lack of information and insufficient environmental resources, that need to be overcome.

The benefits gained from adopting sustainable hazardous waste management will continuously encourage an increasing number of organisations to exert much effort onto it. The success of this initiative depends on a few factors, including readiness of hazardous waste beneficiary, economic and environmental benefits, stakeholders’ pressure, adoption of ISO14001, effects on corporate image, commitment from the top management and incentives and reward.

In the future work, a few experienced hazardous waste handlers from electronic companies will be interviewed to help us identify the overlooked barriers and critical success factors of sustainable scheduled waste management. The primary data will be collected from personnel involved in the management of scheduled wastes amongst electronic manufacturers through the distribution of self-administered questionnaires. This study will use close-ended question method to collect data and measure items by using a five-point Likert scale. The collected data will be analysed using principal component analysis to identify the most important CSFs and barriers for the respondents.

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