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Toward sustainable solid waste minimization by manufacturing firms in Malaysia: strengths and weaknesses

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Abstract Malaysia is facing an increasing trend in industrial solid waste generation due to industrial development. Thus, there is a paramount need in taking practical actions and measurements to move toward sustainable industrial waste management. The main aim of this study is to assess practicing solid waste minimization by manufacturing firms. Analysis showed that majority of firms (92%) dispose of their wastes rather than utilize other sustainable waste management options. Also, waste minimization methods such as segregation of wastes, on-site recycle and reuse, improved housekeeping, and equipment modification were found to have significant contribution to waste reduction ($p < 0.05$). Lack of expertise ($M = 3.50$), lack of enough information ($M = 3.54$), lack of equipment modification ($M = 3.16$), and lack of specific waste minimization guidelines ($M = 3.49$) have higher mean score comparing with other barriers in different categories. These data were interpreted for elaborating on SWOT and TOWS (strengths, weaknesses, threats, and opportunities) matrix to highlight strengths, weaknesses, threats, and opportunities. Subsequently, ten policies were recommended for improvement of practicing waste minimization by manufacturing firms as the main objective of this research.

Keywords Sustainable waste management · Waste minimization · Waste minimization barriers · SWOT and TOWS matrix

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Sustainable development and waste management hierarchy

Moving toward industrialization has engaged many countries in the development of other industrial produce market shares. Due to rising of living standard and increase of the world population, large amounts of wastes are generated (Jalil 2010; Oweis et al. 2005). Majority of manufacturing industries have been forced to find a proper solution for managing their wastes due to rapidly increasing of waste generation and restrictive legislative framework. However, dealing with industrial waste generation cannot be achieved without moving toward a sustainable waste management approach. Sustainable development helps to achieve economic growth

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without compromising the environmental quality by simply reducing the quantity of generated wastes (Bavani and Phon 2009; Ion and Gheorghe 2014).

Meanwhile, sustainable industrial activity should be efficient in using resources that replace non-recyclable with recyclable materials and practice good housekeeping, modify production process and technology, and similar methods. (Gertsakis and Lewis 2003; Staniskis and Stasiskiene 2005). It is necessary for all industries to follow sustainable waste management strategies rather than sending their waste for landfill disposal. However, some industries are reluctant to follow waste minimization strategies as a sustainable technique for waste handling (Haggar 2010). Waste management defines as any strategy and technique for controlling waste generation and handling. Applying appropriate waste management strategies leads to waste minimization, which plays an important role in sustainable development. Waste minimization strategies and control in Malaysia is one of the main objectives in order to achieve the United Nation agenda by emphasizing on human and environment (Mesjasz-Lech 2014; Budhiarta et al. 2012). Meanwhile, source reduction by manufacturing firms helps to protect natural resources, saves energy and money, and reduces any destructive impact on human's life and the environment that is more widely accepted by industries (Shadiya et al. 2012; Sreenivasan et al. 2012).

The 3Rs (Reduction, Reuse, and Recycle) strategy in waste management hierarchy considers the suitable strategy for achieving sustainable development (Agamuthu and Fauziah 2014). Among these 3Rs strategies, waste minimization is located at the highest level in the waste management hierarchy, which is known as the most influential factor in sustainable development. Moreover, it has a major application in process efficiency and saving the manufacturing process, disposal, treatment cost, and reduction of environmental issues (Babu et al. 2009; Pratt and Phillips 2000).

In Malaysia, practicing waste minimization, promotion of reuse and recycling, and 3Rs practices together with using environmentally friendly products are encouraged by the government and emphasized in the 8th (2001–2005) and 9th (2006–2010) Malaysian Plan (Zainu et al. 2015). Techniques of waste minimization include source reduction and recycling techniques. Source reduction includes equipment or technology modification, process modification, feedstock substitution, housekeeping practice, redesign products, and recycling within the process (Basu and van Zyl 2006; Shadiya et al. 2012). Figure 1 below illustrates the waste management hierarchy and common methods for minimizing the wastes at source considering 3Rs component based on the review of different literature.

Current scenarios and challenges of industrial solid waste minimization in Malaysia

There is always a complexity among different researches in terms of solid waste definition (McDougall et al. 2008). It is not easy to establish a sustainable waste management system without providing the detailed information in terms of the waste quantity and the waste origin, composition, and characteristics. It was also reported most of the industries in Malaysia are not willing to provide the information regarding the quantity and composition of wastes from their industrial activities (Nasir and Chong 2001). The daily solid waste generation per capita in Malaysia was estimated approximately 0.85 kg per person daily and it continues to be the major challenge. In Malaysia, industries are in the second place in terms of the waste generation which comprised 25% of total waste generation (Moh and Manaf 2014; Zainu and Songip 2017). Hence, it was reported that most studies regarding industrial waste management in Malaysia focused more on the general picture of solid waste management and there are just a few studies about in-depth industrial solid waste minimization and practices (Mbuligwe and Kaseva 2006; Moh and Manaf 2014). Industrial wastes are categorized into two main categories in Malaysia: hazardous industrial wastes and general solid waste as follows (Kojima and Damanhuri 2009):

- Hazardous industrial wastes: these types of wastes are known as scheduled wastes comprised of a different component of wastes with toxic characteristics. The Department of Environment (DOE) is responsible for managing these types of wastes under the Environmental Quality (Scheduled Wastes) Regulation 1989.
- General solid wastes: these include any non-hazardous solid waste generated within the manufacturing process.

Plastic, paper and cardboard, scrapped metal, glass, wood, rubber, and textile wastes are different types of

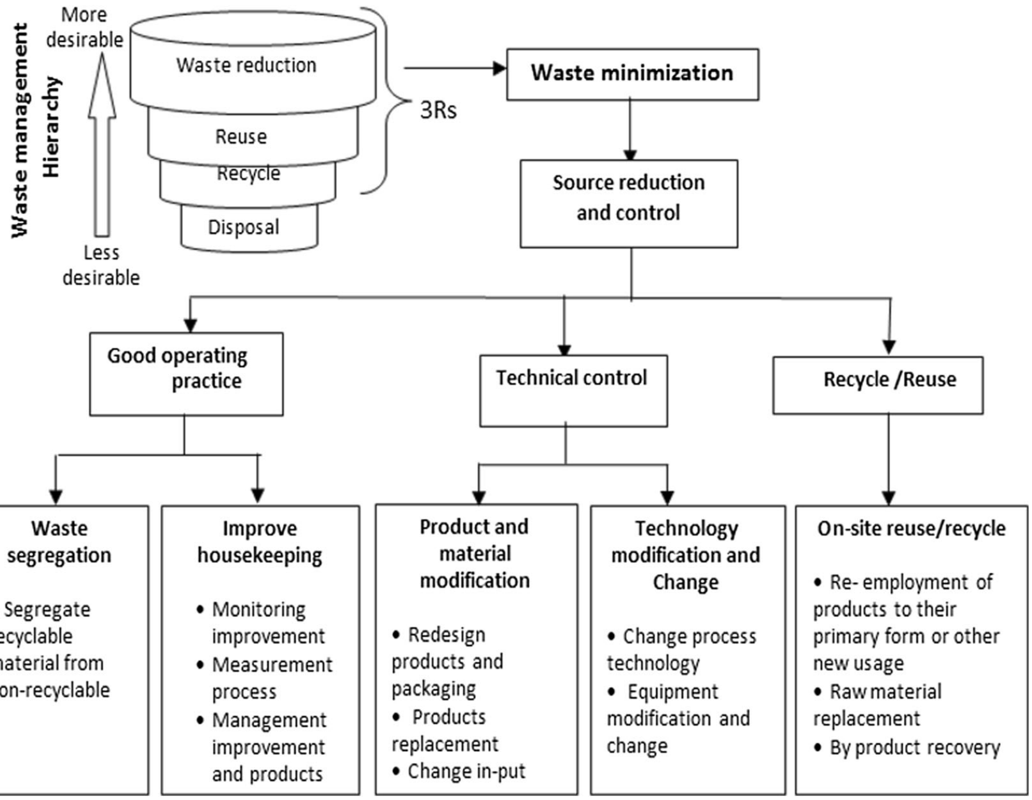

Fig. 1 Conceptual framework for waste minimization methods. Source: modified from Canada (2013), Begum et al. (2007), and Halim and Srinivasan (2002)

industrial solid and non-hazardous wastes generated by manufacturing activities in Malaysia. Among different types of solid wastes, metal and paper wastes are the dominant generated industrial wastes in Malaysia (Ngoc and Schnitzer 2009; Fariz 2008).

The end-of-pipe approach is the basis of the existing management system in Malaysia for controlling generated wastes. In this approach, a high priority is given to treatment and disposal rather than the waste reduction that exacerbates negative impacts on the environment (Kojima and Damanhuri 2009). Approximately, 95–97% of generated solid wastes are sent to the landfills for disposal without doing the proper processing. Due to the increasing cost of handling the wastes, many open dumping sites are created (Behzad et al. 2011; Manaf et al. 2009; MHLG 2006). It was reported that about 40% of wastes disposed into open dumping sites and rivers and just 5% of the wastes were transferred for recycling (Desa et al. 2011; Murad and Siwar 2007). It has also been noted that the lack of regulatory framework and inefficient suitable policy for 3Rs hinder controlling the quantity of generated wastes from manufacturing and efficient waste management (Agamuthu and Fauziah 2011). Practicing 3Rs (Reduction, Reuse, and Recycle) in Malaysia was launched in 1980 with more focus on recycling activities; thus, there are some evidence for no improvement in solid waste management with respect to 3Rs activities (Sreenivasan et al. 2012). There are four main bodies associated with waste management in Malaysia, i.e., the Ministry of Housing and Local Government (MHLG), the Department of National Solid Waste Management, local authorities, and DOE (Ishak 2003). The Ministry of Housing and Local Government (MHLG) and the Department of National Solid Waste Management are major stakeholders of industrial solid waste management (Kojima and Damanhuri 2009). In 2006, the Ministry of Housing and Local Government introduced relevant laws and regulations for persuading waste reduction that is effective in enhancing waste minimization including MHLG 2006 as below:

- Solid Waste Management and Public Cleansing Co-operation Act 2007 (SWMPC Act 672) as the basis of waste minimization concepts.

- National Waste Minimization Master Plan and Action Plan
- Local By-Laws on solid waste management and minimization
- Related regulations for enhancing recycling

The local authority in Malaysia was the main authority for managing solid wastes, but through the SWPCMC Act 2007, private sectors take over responsibilities of solid waste management. The goals of privatization of SWM are solving issues regarding technology, expertise, and illegal dumping and providing the high-quality waste managing services as well as enhancing awareness among different sectors. (Abdullah et al. 2017; Zainu et al. 2015). Prior to this, lack of awareness and poor attitude toward waste management principles hindered the effective practicing of waste minimization (Agamuthu and Fauziah 2014; Hassan et al. 2000).

The main objective of this study is to analyze practicing solid and non-hazardous waste minimization by manufacturing industries together with its strengths and weaknesses in Malaysia. In addition, preventing factors toward waste minimization were determined in this study. Therefore, the findings of this study can provide a useful baseline information and data that is helpful to recommend solutions for the improvement of industrial solid waste minimization practices among Malaysian industries.

Materials and methods

As illustrated in Fig. 2 below, both secondary and primary data are used. Secondary data was used for developing methodology and it was done at the first step of this study to provide the required information that is required for developing the methodology and designing questionnaire. The primary data was collected through a survey questionnaire and was administered to the respondents, i.e., randomly chosen respective manufacturing firms. A concurrent triangulation strategy was used and both quantitative (survey) and qualitative (semi-structured interview) data were collected concurrently for complementary analysis, which is the aim of the parallel mixed methods research design. Mixing approach in this study was applied for the formulation of the SWOT (strengths, weaknesses, opportunities, and threats) and TOWS (threats, opportunities, weaknesses, strengths) matrix.

Study area

This study was conducted in Shah Alam, the capital of Selangor, Malaysia. Selangor is the most populated and developed state in Malaysia where industrial activities are the mainstay of its economy with about 58% GDP. The main reason to choose Shah Alam for the study area is that the highest number of manufacturing industries is located at this area and it is one of the top investment centers contributing tremendously to the economic development of Selangor and indeed Malaysia. In aggregate, the city of Shah Alam has 57 sections. Approximately, there are about 1800 manufacturing firms located in this area comprising different types of industrial activities (MBSA 2013). Solid waste management and minimization are one of the main concerns in Shah Alam city (Omar and Nazrul 2008). The existence of illegal landfill disposal sites in Shah Alam has been reported (MBSA and MBMB 2010).

Design, validity, and reliability of questionnaire

The research instrument is divided into four parts, namely:

- Part A—Demographic information
- Part B—Industrial solid waste generation and composition
- Part C—Industrial solid waste management and minimization methods
- Part D—Waste minimization barriers

Cronbach's alpha procedure was employed for determining the reliability of the instrument. The alpha value for all items in the instrument ranged between 0.70 and 0.92, which indicated the acceptable interrelation between factors (Jang et al. 2005). The content validity of the instruments was established by the consulting a panel of ten experts who had enough experience and knowledge of waste management, minimization, and related laws and policies. They were selected from the academics in universities, consultants, and environmental officers from relevant organizations.

Quantitative data collection and analysis

The population of the study is about 1800 manufacturing firms that are located in Shah Alam industrial areas. The sample size of the study is 317 (95% confidence level)

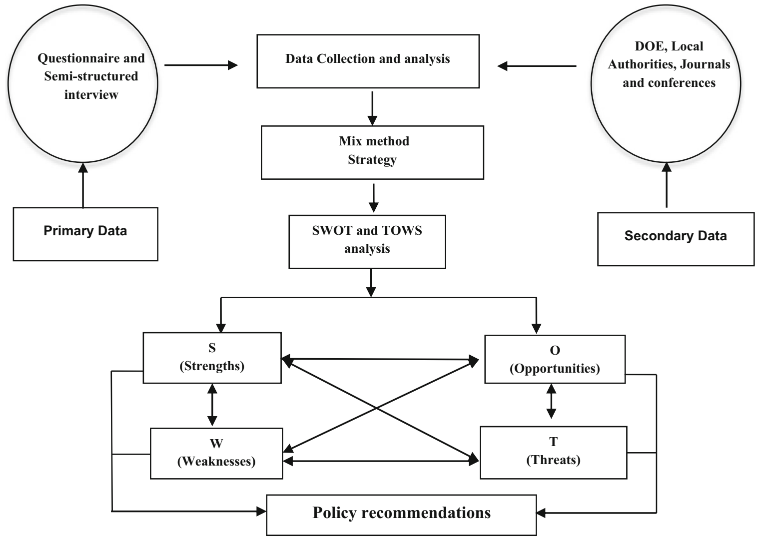

Fig. 2 Research methodology of the study

based on Cochran's formula (Cochran 1977). First, the researcher randomly administered 317 questionnaires to each manufacturing firm of which 250 questionnaires were collected back, out of which 36 questionnaires were not completed satisfactorily. Therefore, 214 completed questionnaires were collected which constitutes a response rate of 67.5%. The response rate of 67.5% is an acceptable response rate as suggested by Rea and Parker (2012) and Baruch and Holtom (2008). The questionnaires were administered to the representatives of each firm who were experts of waste management or the persons with sufficient knowledge regarding the survey questions such as environmental and legal executive, executive of health, safety, and environment (HSE), and safety and environment officer that were introduced by the managing director of the firms. The quantitative data were analyzed using IBM–SPSS 20 software.

Qualitative data collection and analysis

In this study, the qualitative data was used as a supplement for completion of SWOT matrix for policy recommendations. For this purpose, a face-to-face semi-structured interview was carried out among manufacturing firms and relevant solid waste management organizations. Participants were chosen from experts who were engaged in waste management. One group of interviewees was eight respondents from relevant waste management organizations including waste management officers, private contractors, and director generals from the local authorities and private waste management companies. These interviewees were chosen because they have been directly involved in waste management activities and related policies. Another group of interviewees consisted of six respondents from different sizes and types of manufacturing firms who were familiar with waste management aspects and related issues regarding practicing waste minimization in their manufacturing firms. They were from the managing director and the manager responsible for environmental performances. The audio files from 14 interviewees were transcribed and the data were analyzed using a thematic approach including coding, segregation, theme formulation, and tentative findings.

SWOT and TOWS analysis

SWOT and TOWS are widely used in the field of waste management (Mbuligwe and Kaseva 2006; Nikolaou and Evangelinos 2010; Yunus and Yang 2014). The SWOT technique is an effective tool in improving the environmental management and performances among small and medium firms (Seidel et al. 2009). In addition, it is a very useful instrument for situational assessment and for a successful strategy formulation (Pesonen et al. 2001). It can evaluate the internal and external conditions concurrently recording all potentials and opportunities (Yunus and Yang 2014). TOWS analysis is considered as the next step of SWOT analysis which provides a logical combination between internal (strengths and weaknesses) and external parameters (opportunities and threats). In other words, it is a helpful tool to think about the possible options for pairwise comparisons (Felice et al. 2013).

In this study, SWOT matrix was used from both quantitative and qualitative investigations to highlight strengths and weaknesses existing in the manufacturing firms. In addition, the opportunities and threats in the external environment were highlighted with respect to the solid waste minimization practice. Subsequently, TOWS matrix strategy was used to provide a logical combination between internal factors (strengths and weaknesses) and external factors (opportunities and threats) as highlighted in the study of Chavan (2005) and Felice et al. (2013).

Results and discussion

Profile of studied manufacturing industries

Table 1 below shows the profile of 214 studied manufacturing industries. Out of the 10 types of industrial activities, machinery and equipment industries had the highest number of the respondents with 18.69% (n = 40) of responses. Out of the 214 industrial firms, about 28% (n = 61) of respondents were from small-size firms, 39% (n = 83) from medium-size firms, and 33% (n = 70) from large-size firms (number of employees > 150).

Statistically, 39.25% of manufacturing industries stated to have ISO 14000 series as environmental certificates (n = 84), but 60.74% of them did not obtain any environmental certificate (n = 130).

Waste management and minimization practice by manufacturing firms

In this part, respondents were asked to provide the percentage value for practicing waste management options and frequency of practicing each method of waste minimization. Table 2 below shows the results of descriptive statistics of waste management options practiced by firms. As shown in Table 2, approximately 92% of the 214 firms disposed their generated wastes (n = 199) ranging from 5 to 100%. The mean score for disposal is higher than that for other methods (M = 39.95%).

In line with these findings, Agamuthu et al. (2009), Kojima and Damanhuri 2009), and Desa et al. (2011) have revealed that the end-of-pipe system is the most usable option for waste management in Malaysia and approximately 95% of solid wastes are sent to landfills. A low level of current recycling rate for solid wastes (5%) was also emphasized in their studies.

Table 1 Manufacturing firms profile

Manufacturing firms	Frequency (N = 214)	Percentage
Industry type		
Basic metal	37	17.28
Food and beverage	20	9.34
Chemical	34	15.88
Machinery and equipment	40	18.69
Rubber-based	17	7.94
Wood-based	13	6.04
Electrical and electronic	29	13.55
Non-metallic mineral	8	3.73
Medical device	8	3.73
Textile and apparels	8	3.73
Industry size (employees number)		
Small	61	28.50
Medium	83	38.78
Large	70	32.71
Environmental certificate (ISO 14000 series)		
Yes	84	39.25
No	130	60.74

Size: small (less than 50 employees), medium (from 50 to 150 employees), and large (more than 150 employees)

5-point Likert scales were used to provide several frequency options for minimization methods practice as 0, not practice at all; 1, seldom practice; 2, sometimes practice; 3, often practice; and 4, most frequently practice. According to Fig. 3, methods such as on-site recycle and reuse, improve housekeeping, and segregation of wastes at source have been practiced by 67%, 63%, and 62% of firms respectively. Those methods can be considered as the most common methods practiced by the firms. However, the mean scores of this methods' practicing range from 2.37 to 2.60, which imply a moderate level of practicing. Fewer numbers of firms (28% to 15%) have practiced methods dealing with technological change or modification such as process modification (change). The total mean score of this methods' practicing ranges from 1.25 to 1.52.

The findings of this study are in contrast with the findings of waste minimization practice as reported by Clelland et al. (2000) which inferred that methods including modifying production process and input material

Table 2 Solid waste management methods practiced by manufacturing firms

Waste management options	Percentage of firms (%)	Minimum level of practicing	Maximum level of practicing	*M* (%)	SD
Disposal	92% (199)	5	100	39.95	30.56
Recycle*	73% (156)	2	90	30.09	27.41
Reuse*	40% (87)	2	100	9.03	16.67
Source reduction (minimization)	79% (170)	2	80	20.97	16.24

N = 214, *M*, mean of waste management methods, *SD*, standard deviation; *Off-site reuse/recycle

modification have more application among firms. Similarly, Raouf and Jafarzadeh (2005) stressed these two methods as the most applicable methods in their study. It was observed that using a less hazardous material as an input material in one of pharmaceutical manufacturing has extensive application in the production process.

Contribution of waste minimization methods in waste reduction

A multiple linear regression analysis was performed to determine the effect of waste minimization methods on waste reduction at source. As revealed in Table 3, segregation of wastes ($\beta = 0.223$, $t = 3.303$, $p = 0.001$), on-site recycle and reuse ($\beta = 0.205$, $t = 3.315$, $p = 0.001$), equipment modification ($\beta = 0.176$, $t = 2.798$, $p = .006$), and improve housekeeping ($\beta = 0.146$, $t = 2.090$, $p = 0.038$) significantly contributed to waste reduction respectively. Other methods such as product modification/change, change/modify process technology, redesign packaging, and change/modify input material did not contribute significantly to waste reduction ($p > 0.05$).

In line with the aforementioned finding, Rao and Prabhakar (2013) also showed segregation of wastes and good housekeeping have significant contributions in their industrial activity. In another study, about 50% of wastes were reduced by improved housekeeping and about 75% decreased by on-site recycling (Staniskis and Stasiskiene 2005). In a similar vein, on-site recycle and reuse method was explored by Begum et al. (2007) as the most effective method in reducing the waste quantity at the source. However, the effectiveness of equipment modification has been mentioned in the study of Musee et al. (2007).

Barriers to waste minimization practice

The Likert scale questions in this part are used in order to measure the intensity of the respondents' opinion toward the seriousness of barriers in practicing waste minimization. Respondents were asked to rank the seriousness of barriers (20 items) which divided into four categories, i.e., awareness and human capability (5 items), information (4 items), technology (6 items), and barriers regarding costs, time, and governance

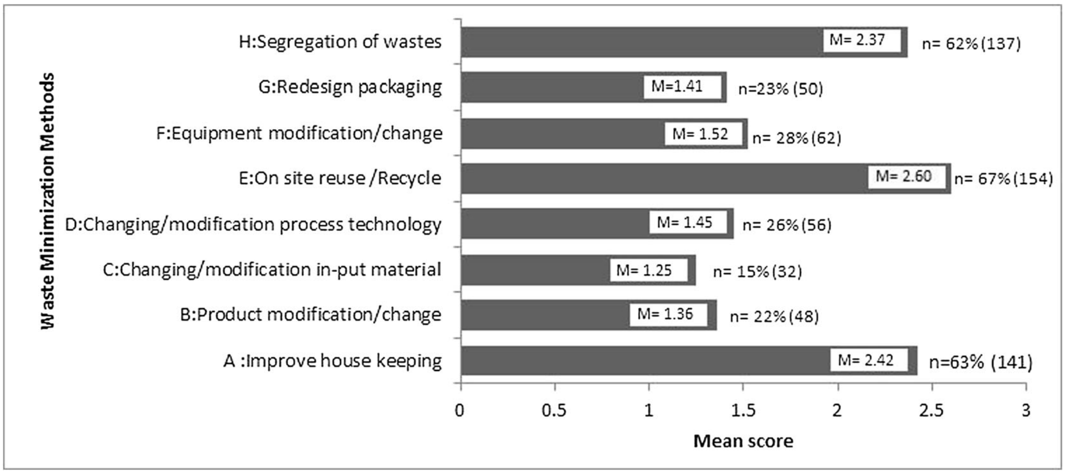

Fig. 3 Level of waste minimization practiced by firms

Table 3 Multiple regression of waste minimization methods effectiveness

Independent variables	Beta	*t* value	*p* value
A: improve housekeeping	0.146	2.090	0.038
B: product modification/change	0.105	1.674	0.096
C: changing/modification input material	0.007	0.110	0.913
D: changing/modification process technology	0.051	0.835	0.405
E: on-site reuse/recycle	0.205	3.315	0.001
F: equipment modification/change	0.176	2.798	0.006
G: redesign packaging	0.047	0.759	0.448
H: segregation of waste	0.223	3.03	0.001

The regression model consists of eight independent variables, namely, A, B, C, D, E, F, G, H and is significant $F\,(8, 205) = 13.428$, $p < 0.05$, $R^2 = 0.34$, range of VIF from 1.18 to 1.51

factor (5 items). Figure 4a–d below illustrates the results of the descriptive analysis of barriers preventing industries from practicing in waste minimization.

As shown in Fig. 4a, lack of expertise and manpower (AW5) among other barriers has a higher mean score ($M = 3.50 \pm SD = 1.07$). It was followed by the AW1 (lack of waste minimization awareness among employees) ($M = 3.44 \pm SD = 1.06$), AW4 (lack of trained staff or personnel) ($M = 3.03 \pm SD = 1.03$), AW2 (lack of belief in practicing waste minimization) ($M = 2.78 \pm SD = 0.87$), and AW3 (lack of cooperation among staff) ($M = 2.64 \pm SD = 0.88$). Figure 4b revealed that INF4 (lack of sufficient information and basic data) ($M = 3.54 \pm SD = 1.16$) has the highest mean score in the category of information barriers. It was followed by INF1 (lack of accurate information about benefits of waste minimization) ($M = 3.29 \pm SD = 1.08$), INF2 (lack of technical information) ($M = 3.00 \pm SD = 0.95$), and INF3 (lack of legal information) ($M = 2.93 \pm SD = 1.06$) respectively. Figure 4c implies on barriers regarding technologies in which TECH 4 (lack of equipment modification) ($M = 3.16 \pm SD = 1.23$) has the highest mean score in this category. It was followed by TECH 1 (old production process technology) ($M = 2.83 \pm SD = 1.03$), TECH2 (lack of process control technology) ($M = 2.79 \pm SD = 0.99$), TECH 5 (lack of material modification technology) ($M = 2.68 \pm SD = 0.83$), TECH 3

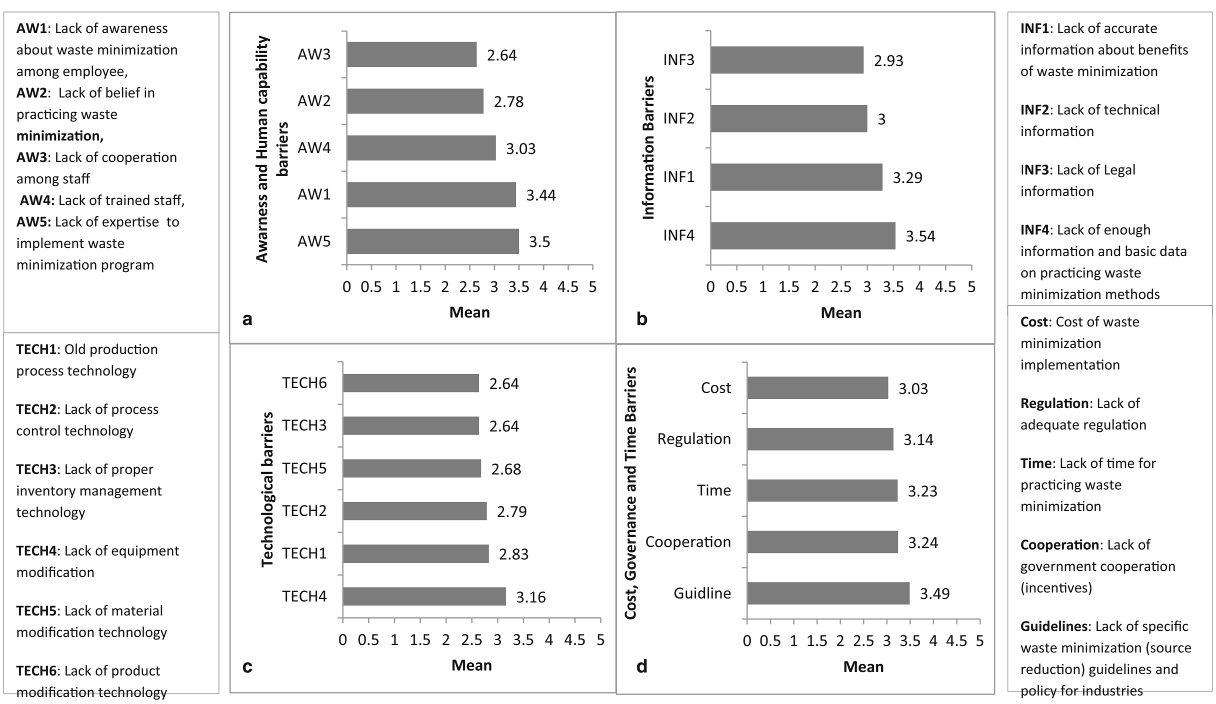

Fig. 4 **a** Awareness and human capability barriers. **b** Information barriers. **c** Technological barriers. **d** Cost, governance, and time barriers

(lack of proper inventory management technology) ($M = 2.64 \pm SD = 0.82$), and TECH 6 (lack of product modification technology) ($M = 2.64 \pm SD = 0.82$). Figure 4d shows that the higher level of barrier in this category relates to the lack of specific waste minimization guidelines and policy ($M = 3.49 \pm SD = 1.08$). It was followed by lack of government cooperation (incentives) ($M = 3.24 \pm SD = 1.07$), lack of time ($M = 3.23 \pm SD = 0.99$), and lack of adequate regulation ($M = 3.14 \pm SD = 1.04$) and cost ($M = 3.03 \pm SD = 0.92$).

This finding is in line with the findings by Barr (2007), Barr et al. (2001), and Koefoed and Buckley (2008), which reveals that lack of knowledge, concern, and insufficient training influences the practicing of waste minimization. In addition, Ali et al. (2012) have mentioned that lack of awareness is a major preventive factor in practicing waste minimization. In addition, Mbuligwe and Kaseva (2006) laid emphasis on the lack of information and data on industrial solid waste management as a significant barrier. Similarly, lack of data and information regarding the solid waste generation and composition has been recognized as one of the fundamental barriers in establishing a sustainable waste management system in Malaysia (MHLG 2006; Moh and Abd Manaf 2014).

With respect to the technological barriers, Babu et al. (2009) and Agamuthu et al. (2007) have argued about technology barrier as the hindrance to waste management. Furthermore, Musee et al. (2007) revealed that lack of technology modification is one of the main problems in waste reduction in his study. Smith and Ball (2012) and Ngoc and Schnitzer (2009) have implied that a lack of guidelines and regulatory frameworks prevents manufacturers from moving toward sustainable industrial activities in Asian countries. In addition, lack of financial incentives from the government was highlighted in the study of Tam (2008) as a major burden in waste minimization.

Semi-structured interview

Table 4 below shows the main themes and findings of the semi-structured interview from relevant waste management organizations and manufacturing firms. The main themes of interviews include types and quantity of industrial solid wastes, main options for handling industrial solid waste, barriers in industrial solid wastes management and minimization, enforcement effectiveness, and waste management policies, the role of stakeholders in waste minimization practices, and benefits from practicing waste minimization. The results determine ineffective waste management and minimization strategies.

Formulation of SWOT and TOWS matrix

Both results and findings from the semi-structured interview and structured questionnaire were used for SWOT matrix formulation. In the SWOT matrix, strengths and weaknesses existing in the manufacturing firms were highlighted. In addition, the opportunities and threats in the external environment were found by semi-interviewing the people in charge of the relevant organizations. Table 5 illustrates the summary of SWOT analysis based on the interpretation of the quantitative and qualitative findings collected in this study.

In TOWS matrix, the SO strategies use the firm's internal strengths to take advantage of external opportunities, WO strategies aim to improve internal weaknesses by taking advantage of external opportunities, ST strategies use a firm's strengths to avoid or reduce the impact of external threats, and the WT strategies are defensive tactics for reducing both weaknesses and threats (Chavan 2005). Details of TOWS matrix is given in Table 6 below. It provides a logical combination between internal (strengths and weaknesses) and external factors (threats and opportunities). Therefore, preliminary policies suggested for improving industrial solid waste minimization practice at source by manufacturing firms in the studied area.

Policy recommendations for improvement of practicing waste minimization

Figure 5 illustrates the framework of policy recommendations for improvement of solid waste minimization practiced by manufacturing firms in Malaysia. The policies that were validated by the panel of experts serve as a guide to policymakers, local authority, manufacturers, private waste management companies, and consultants.

S-O1: Increase in research and consultancy programs

The strengths and opportunities highlighted in the study indicated the need for more research in waste minimization methods. To be in line with vision 2020, more institutional support is required to raise awareness on the concepts of waste minimization at source and methods of waste minimization. As stated in the SWOT table, methods including segregation of wastes, on-site recycle/reuse, and improvement in housekeeping with the significant contribution to

Table 4 Main themes and findings of interview from manufacturing firms and related waste management organization

Main theme of the study	Findings
Types and quantity of industrial solid wastes in the studies area	• Rarely published data about the trend of industrial solid waste generation
Widely used option for managing industrial solid wastes	• Recycling
	• Disposal
Enforcement effectiveness	• Not efficient and strict enforcement
	• Not mandatory and effective policy and guidelines
Issues in solid waste management and minimization stated by organization opinion	• Lack of environmental attitudes and concerns
	• Insufficient skillful manpower
	• Lack of monitoring
	• Ineffective policy
	• Inadequate and no strict penalty
	• Lack of reliable data
	• Private arrangement of solid waste management
Stakeholders' role in the improvement of solid waste management and minimization	• Training and workshops
	• Encouragement programs
	• Advice and consultation
	• License issuance
Preferable option of managing waste by firms	• Minimizing and recycling
	• Disposal
Benefits were achieved by practicing waste minimization	• Cost saving
	• Increase environmental concern
Waste minimization policies and guidelines followed by firms	• Company policy
	• No specific guidelines and policy
Barriers in practicing waste minimization among firms	• Lack of awareness and cooperation among staff
	• Insufficient expertise, time, and monitoring
	• Lack of technological modification, space, and funding
	• Inadequate enforcement and incentive programs

waste reduction have been practiced more than the other methods; however, these methods need to be practiced more often. Therefore, the effectiveness and level of practicing these methods are improved by more consultation supports and awareness-raising campaigns.

S-T1: Organizational restructuring

Each manufacturing firm should consider restructuring to ensure specific units for improvement of waste minimization techniques and technology modification. Experts need to be employed to solve problems regarding practicing waste minimization. This unit should be under the direct supervision of the general director. As revealed earlier in the SWOT table, an intention to practice waste minimization on the one hand and unsteady involvement in specific training and encouraging for waste minimization as threats, on the other hand, implied the importance of establishing the waste management units in firms.

S-T2: Establishing incentives and motivation

As revealed by the SWOT analysis, there is an intention for practicing waste minimization. In addition, some of the methods of waste minimization have been practiced

Table 5 Summary of SWOT analysis regarding practicing waste minimization by manufacturing firms

Internal factors	Strengths	**S1** Recycling and minimization intention for saving costs
		S2 Most commonly practiced waste minimization methods such as on-site reuse/recycle, improved housekeeping, and waste segregation
		S3 Incorporation of a significant contribution of some methods such as on-site reuse/recycle, improved housekeeping, waste segregation, and equipment modification in waste reduction
	Weaknesses	**W1** Higher level of waste disposal and lower level of waste minimization
		W2 Less frequently practiced methods such as equipment modification, change input material, product modification, change process technology, and redesign packaging
		W3 Low contribution of methods dealing with changing and modifications of material, process technology, and products in waste reduction
		W4 Barriers with regard to information, awareness, and human capability related to waste minimization
		W5 Limited application and modification of new technology for waste minimization
		W6 Poor attitude and less environmental concerns about practicing waste minimization
External factors	Opportunities	**O1** Existing organization related to the waste management programs
		O2 Existing potential for providing consultation and holding workshops
		O3 Existing experts and fresh graduates of waste management in academic areas and related waste management organization
	Threats	**T1** Lack of updated and comprehensive data on waste minimization
		T2 Inadequate cooperation and incentive programs
		T3 Insufficient waste minimization regulation and policy
		T4 Lack of strict monitoring and enforcement
		T5 Lack of provision of continues training on waste minimization

which can be improved by the encouragement from local authorities. The encouragement should not be limited to recycling activities. It should also include encouraging manufacturing firms to adopt suitable waste minimization methods for reducing wastes at source based on their industrial activities.

The governmental organization should strengthen encouragement and motivation programs for manufacturers to incorporate modifying methods of minimization and technologies for reduction of wastes at source. The government should reward the companies with the best environmentally friendly practices. This will encourage regular capacity building in order to enhance segregation of wastes, housekeeping, and on-site reuse and recycling which were more practiced compared with the other methods. For instance, it is suggested that the government should give tax incentives to industries based on the quantity of wastes reduced by applying waste minimization methods at the source.

W-O1: Enhancing skills and innovative capability

As highlighted in the SWOT tables, lack of waste minimization awareness, lack of manpower and expertise, and lack of accurate information respective to waste minimization principles are the hindrance to effective waste minimization practice. Therefore, an expert team in the field of waste management and waste minimization practice should implement educational and training programs for both managers and employees in manufacturing firms.

W-O2: Developing technology and modification

With respect to the improvement of technological aspects of waste minimization as highlighted in the SWOT table, related organizations and manufacturers should well operate and maintain sustainable technologies. Manufacturing firms, with the assistance of related solid waste management organizations and the government, should modify old

Table 6 TOWS matrix strategy of practicing waste minimization by manufacturing firms

TOWS matrix	Strengths	Weaknesses
Opportunities	SO strategy: use a firm's internal strengths to take advantage of external opportunities.	WO strategy: improving internal weaknesses by taking advantages of opportunities
		W-O1 policy: enhancing knowledge, skill, and innovative capability (W2, W3, W5, O3)
	S-O 1 Policy: Raising research and consultation (S1,O1,O2,O3)	W-O2 policy: developing technology design and modification (W2, W3, W4, O1, O3)
		W-O3 policy: inaugurate collaboration and cooperation (W1, W5, W7, O1, O2)
		W-O4 policy: financial support (W2, W6, W7, O1, O2)
Threats	ST strategy: use a firm's strengths to avoid or reduce the impact of external threats	WT strategies: defensive tactics directed at reducing internal weaknesses and avoiding environmental threats
	S-T1 policy: organizational restructuring (S1, T1, T2, T5)	W-T1 policy: promulgating good governance (institutional and legislative) (W1, W2, W4, W5, W6, W7, T3, T4)
	S-T2 policy: establishing incentives and motivating (S1, S2, S3, T2)	W-T2 policy: implementing supervision and monitoring (W1, W2, W3, W5, W6, W7, T4, T5)
		W-T3 policy: launching information and waste data tracking system (W2, W3, W4, W5, W6, W7, T1)

technologies that are responsible for more waste generation. This is to ensure that technologies applied by manufacturing firms are clean, generate less waste, and practice environmental friendly approaches and the manufacturing team should also assure equipment and machine maintenance.

W-O3: Inaugurate collaboration and cooperation

Based on the barriers that were highlighted in the SWOT table, sustained cooperation among all stakeholders in solid waste management is necessary. Industries with successful implementation of waste minimization should share their experiences with other interested stakeholders through periodic seminars and workshops. Improving collaborations between industries and experts in related solid waste management organizations and institutional and academic centers must be encouraged to apply new technologies and invest in research and development.

W-O4: Financial support

The Malaysian government should provide specific financial support for designing and employing new technologies, production process modification, and improving the quality of input materials. Despite practicing some methods to reduce waste at source, firms need to invest in additional equipment and activities in order to improve the effectiveness of those methods.

W-T1: Promulgating good governance (institutional and legislation)

Based on threats highlighted in the SWOT table, the national policies and guidelines should be formulated to enhance solid waste minimization at source based on each type of manufacturing firm at the national level. In addition, policies on 3Rs should give more priority to reduction and introduce specific waste minimization methods. Moreover, the local authority should define a standard and limits for the solid waste generation by each manufacturing firm in both process and non-process wastes and set penalties according to the limits set for the solid waste generation.

All manufacturing firms should enforce 3Rs policies, guidelines, and environmental management system. From the interview results, the majority of firms' manager implied that they were too busy to spend time on related waste minimization programs; they also neglected to allocate space for segregated wastes. By providing strict enforcement of regulations and policies, relevant stakeholders expected to spend more time and

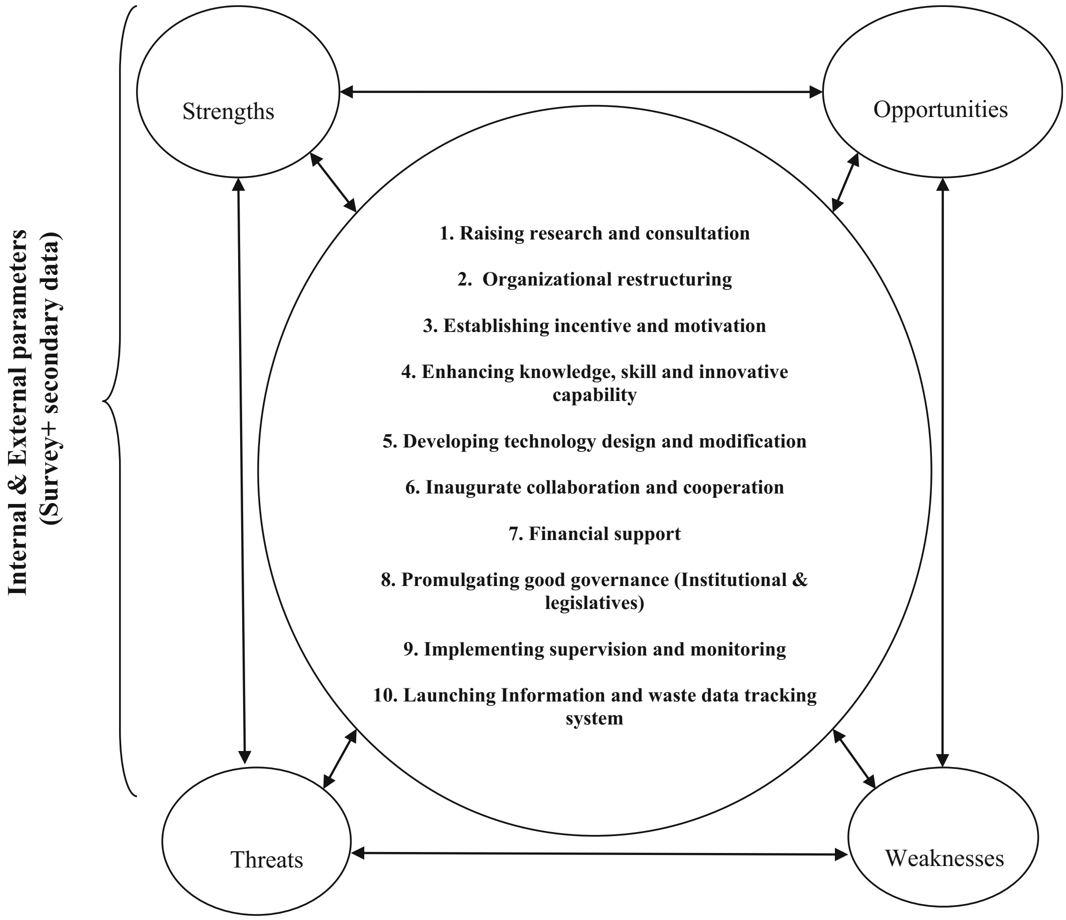

Fig. 5 Policy recommendations for improvement of practicing waste minimization by manufacturing firms

money to train staff, to establish an awareness campaign, and to allocate the specific area for saving segregated wastes. Strict enforcement will obligate industries to take waste minimization program as a serious matter. Relevant agencies should synchronize solid waste management-related regulations. Therefore, industries need to practice strengthening and amendment of the regulations and policies for more efficient implementation of waste reduction methods.

W-T2: Implementing supervision and monitoring

The local authority or other relevant agencies should conduct the comprehensive evaluation of the effectiveness of current waste minimization practices. Furthermore, they should also evaluate and supervise the firm's compliance with regulations, related policies, and effectiveness of waste minimization practices. Besides that, the activities and commitment of private contractors in their implementation should be audited. For a better monitoring, instead of manufacturing firms, the local authority should appoint private contractors for each industrial state or each type of industrial activity. Moreover, internal monitoring by the managing team on practicing waste minimization and related principles should be conducted periodically.

W-T3: Launching information and waste data tracking system

As revealed earlier, there is an information gap in relation to solid industrial waste generation. As a result, designing an efficient system for waste minimization is not possible. Therefore, the local authority should establish a system to collect data periodically on solid industrial wastes generated by different manufacturing firms, the quantity of wastes reduced by practicing of each minimization method, and effectiveness of minimization methods in source reduction. In addition, manufacturing firms should update their statistics and database regarding the information on the solid waste generation and practiced waste minimization methodologies.

Conclusion

Practicing solid waste minimization by manufacturing firms was extensively explored and evaluated in this study. A wide range of qualitative and quantitative data was collected and processed from industries, and concurrent triangulation method was used for the formulation of SWOT, TOWS matrix, and policy recommendations.

It was found that methods such as segregation of wastes, on-site reuse/recycle, and improve housekeeping were practiced more than other methods. Moreover, the findings implied that four methods of waste minimization, i.e., segregation of waste, on-site recycle and reuse, equipment modification, and improving housekeeping, had a positive and significant contribution to waste reduction among manufacturing firms in Shah Alam. Besides, it was shown insufficient expertise, lack of awareness among employees, lack of reliable information and data, old production process, lack of proper inventory techniques, lack of equipment modification, inefficient government cooperation, and ineffective policy and guidelines are the most critical items to achieve.

This study is the first of its kind to integrate the common methods that reduced the waste at the source of generation by focusing on industrial solid wastes. Findings of this study provide useful baseline data and information and expand the literature on the industrial solid waste generation and waste minimization practices for further studies. This study has taken the in-depth look at practicing solid waste minimization, its effectiveness, barriers, and important solutions and approaches as the most sustainable component of 3Rs by manufacturing industries in Malaysia. Recommended policies and strategies for improvement of solid waste minimization by manufacturing industries can be serving as a guide for policymakers, local authority, manufacturers, private waste management companies, and consultants. The findings of this study encourage and convince waste management companies to invest in waste minimization practices instead of spending money on development of sanitary landfills and recycling activities.

The findings of this study also highlighted the importance of waste reduction at source and the existing weaknesses and issues of current waste minimization practice in Shah Alam industrial area. Therefore, the researcher concluded that this study can attract more attention and concern to waste reduction at source from disposal and recycling activities.

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