Chemosphere 303 (2022) 134767

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

The development of sustainable IoT E-waste management guideline for households

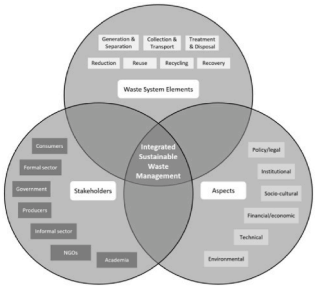
Marym Mohamad Razip [a], K.S. Savita [a,*], Khairul Shafee Kalid [a], Mohammad Nazir Ahmad [b], Maryam Zaffar [c], Eidia Erriany Abdul Rahim [d], Dumitru Baleanu [e,f,g,**], Ali Ahmadian [h,i]

[a] Department of Computer and Information Sciences, Positive Computing, Universiti Teknologi PETRONAS, Perak, Malaysia
[b] Institute of IR4.0, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia
[c] Faculty Of Computer Science, IBADAT International University Islamabad, Pakistan
[d] POIS Sdn. Bhd., Malaysia
[e] Department of Mathematics, Faculty of Arts and Sciences, Cankaya University, Ankara, Turkey
[f] Lebanese American University,11022801, Beirut, Lebanon
[g] Department of Medical Research, China Medical University Hospital, China Medical University, Taichung, Taiwan
[h] School of Mathematical Sciences, College of Science and Technology, Wenzhou-Kean University, Wenzhou, China
[i] Department of Mathematics, Near East University, Nicosia, TRNC, Mersin, 10, Turkey

HIGHLIGHTS

- To propose Sustainable IoT E-Waste Guideline for Household caters.
- To devise a strategy for the development and implementation of IoT projects.
- To develope the guideline of Sustainable IoT E-waste Management for Household.
- To introduce new phenomenon called "IoT E-waste".

GRAPHICAL ABSTRACT



ARTICLE INFO

Handling Editor: Pau-Loke Show

Keywords:
Sustainable
E-Waste
Household
Guideline
Internet-of-Things
Society
Policymakers

ABSTRACT

The introduction of new technology, such as the Internet of Things (IoT), entails a growth in digital devices, which could ultimately result in a high amount of electronic trash (e-waste) production if they are not appropriately managed. Apart from that, the regulation on possible "IoT E-waste" generation is yet to be regulated, probably due to the new development and implementation of IoT globally. Hence, this paper proposed a Sustainable IoT E-waste Management guideline for households. This guideline could assist government agencies and policymakers in their strategies, planning, development, and implementation of a sustainable household IoT e-waste management initiatives in Malaysia. This study is an exploratory study that adopts a qualitative case study research method. The guideline was developed based on the Integrated Sustainable Waste Management (ISWM) Model. This guideline contributes to Malaysia's sustainability agenda in reducing carbon emissions intensity towards 2030 by 45 percent.

* Corresponding author.
** Corresponding author. Department of Mathematics, Faculty of Arts and Sciences, Cankaya University, Ankara, Turkey.
E-mail addresses: savitasugathan@utp.edu.my (K.S. Savita), dumitru@cankaya.edu.tr (D. Baleanu).

https://doi.org/10.1016/j.chemosphere.2022.134767
Received 6 February 2022; Received in revised form 20 April 2022; Accepted 25 April 2022
Available online 5 May 2022

1. Introduction

The Internet of Things (IoT) is being utilised in numerous industries for minimising carbon emissions and energy usage. In the twenty-first century, the number of internet-connected gadgets is increasing at an alarming rate (Pereira et al., 2013). Statista, a statistics service, and Gardiner predict that the number of linked devices will reach 30 billion by 2020 (Statista, 2016). However, according to (Sorrell, 2020) and (i-SCOOP, 2021), the number of connected IoT devices is likely to hit 46 billion the following year. Furthermore, the number of devices internet-connected predicted by Cisco reached 25 billion by 2015 and 50 billion by 2020 (Benkhelifa et al., 2014), with the IoT's worth estimated to be USD14.4 trillion (equivalent to more than RM59 trillion) between 2013 and 2022 (Gardiner, 2014). Thus, it is projected that internet-connected devices could further outnumber humanity by a factor of two (Nonnecke et al., 2016).

Hence, using IoT sensors and devices with a number of internet-connected devices will emulate massive environmental impacts than humanity can predict, including massive electrical consumption, carbon emissions, and electronic waste (E-waste) generation when sensors, hardware, and devices are abandoned. Roughly 10–15% of total generated planned waste in 2012 was produced from Malaysia, and this figure is projected to rise if domestic E-waste collection is completely established (Suja et al., 2014). Malaysians reportedly threw out one million tonnes of E-waste each year (The Star Malaysia, 2017) in 2017. Furthermore, although the Department of Environment (DOE) has produced regulations on E-waste, it is a truth that most of the E-waste is disposed of within landfills and incinerators (The Star Malaysia, 2017) that are causing harm to the land and environment. Hence, understanding the interactions between the value of IoT applications and the environmental impacts of IoT is a significant environmental compromise towards sustainability.

Industrial and household e-waste are the main e-waste streams in Malaysia. Industrial e-waste is produced in industrial facilities through its electrical and electronic equipment whereas household e-waste is produced from residences and commercial institutions. This study focuses on e-waste that are generated from the disposal of IoT appliances in household in Malaysia. Example of IoT appliances in household are IoT home automation appliances that can be electronically controlled through the Internet.

E-waste is hazardous to humans and the environment as it contains toxic additives such as mercury that damages human brain and coordination system. According to UN's Global E-waste Monitor 2020, as reported by (Statista, 2016), a record 53.6 million metric tonnes (Mt) of electronic waste was generated worldwide in 2019, up 21 per cent in just five years. The report also predict that the world's E-waste will reach 74 million MT by 2030 due to higher consumption rates of electrical and electronic equipment and short life cycles. This is a clear indication that the Sustainable Goals Development as highlighted by United Nations in 2015 are not sufficiently implemented. This highlights the urgency of addressing the issue of E-waste management particularly in today's digitally connected world.

Malaysia produced an approximately 10–15% of total generated scheduled waste and expected to increase when the collection of household E-waste is fully implemented (Ismail and Hanafiah, 2021; Yamashita, 2018). In 2017, it is reported that Malaysians throw away one million tonnes of E-waste every year (The Star Malaysia, 2017). Although guidelines on e-waste have been produced by the Department of Environment (DOE), it is a fact that most E-waste goes to landfills and incinerators (Awang, 2013) which will end up contributing harm to the land and environment. United Nations University reported that Asia produces 18.2 million metric tonnes in 2016 which is 40.7% of the global total e-waste. However, only 15% of Asia's e-waste is collected and recycled. In the Southeast Asian region, Malaysia is the second biggest e-waste producers. According to Malaysian Department of Environment (DoE), there is an increased number of e-waste yearly from 2010 until 2020 (Awang, 2013). The increased number of electronic devices owned by Malaysians such as mobile phones, televisions, air conditioners, contributed to the increased amount of e-waste in the country.

It was observed that few developing countries have developed and drafted regulations on household hazardous waste (including E-waste) (Mmereki et al., 2014). Unfortunately, some E-waste and hazardous household waste are almost managed as municipal waste (Aprilia et al., 2013; Mmereki et al., 2016) including in Malaysia. According to the Department of Environment (DoE), the regulation enforcement on E-waste management is currently only for industrial E-waste. In Malaysia, there is no legal mechanism for the control and management of e-waste generated from households. Materials recovery facilities in Malaysia received more industrial E-waste than that from households (The Star Online, 2019). In Malaysia, there is no formal system to recover and dispose household e-waste (Leoi, 2019). This leads to the government drafting a policy and regulation focusing on household e-waste. However, even with the regulation being drafted, it only focuses on six household devices which do not or have minimum involvement on consumer IoT devices or those with internet connectivity. Thus, it can be concluded that, currently, there is a lack of a guideline to manage e-waste generated from IoT embedded devices among households in Malaysia. Therefore, the objective of this paper is to propose an IoT e-waste management guideline for household in Malaysia. This guideline can be used by government agencies and policymakers in their strategies, planning, development, and implementation of a sustainable household IoT e-waste management initiatives in Malaysia. This study contributes to Malaysia's goal of reducing carbon emissions intensity by 45 percent by 2030.

2. Literature review

2.1. Definition of "E-waste", "Household E-waste"and "Household IoT E-waste"

Waste can be categorized into several types. According to the Department of Environment (DOE), there are two types of wastes, namely "Municipal Waste" and "E-waste". There are subs of E-waste, such as industrial E-waste and household E-waste. End-of-life or post-consumer electronics, often known as Waste Electrical and Electronic Equipment (WEEE), are referred to as E-waste (Khan, 2016). The definition of E-waste as waste material derived from electrical and electronic assemblies containing components such as accumulators, mercury switches, glass from cathode ray tubes and other activated glass, or poly-chlorinated biphenyl-capacitors, or contaminated with cadmium, mercury, lead, nickel, chromium, copper, lithium, silver, manganese, or polychlorinated biphenyl-capacitors (Department of Environment Malaysia, 2008). The Department of Environment (DoE) defines "household E-waste" as E-waste originating from household, commercial and institutional units (Ab Rahman, 2018).

IoT E-waste is the End-of-Life (EOL) of IoT embedded devices which include consumer IoT devices with sensors and interactive functionalities. Thus, "Household IoT E-waste" is regarded as E-waste generated by unwanted or EOL IoT devices that are embedded in houses, which implies all hardware parts, electrical circuits, and sensors used. Therefore, IoT E-waste is a phrase used to describe the phenomena of increasing E-waste in tandem with the growth of IoT embedded devices. Furthermore, since sensor is one of the most critical components in an IoT device, it could be one of the contributing factors towards the production of the "Household IoT E-waste" phenomena.

2.2. E-waste in Malaysia

E-waste was generated the most in Asian countries as reported in 2016, followed by Europe, America, Africa, and Oceania. By far, the E-waste generation in 2008 was around 688,000 metric tonnes, with an

anticipated increase to 1.11 million metric tonnes by 2020 in Malaysia. (Ab Rahman, 2018). The United Nations University (UNU) estimated that Malaysia generates approximately 250,000 tons of E-waste every year at the rate of 7.8 kg per inhabitant, which also interprets that consumption of electrical and electronic products will rise steadily, especially with the growth of mobile phone adoption. According to the World Economic Forum, fifty million tonnes of e-waste are produced each year, but only 20% of this is recycled, with the rest being burnt or disposed of in landfills. The research was conducted, and Malaysia produces about one million tons of E-waste out of that amount. Moreover, only about 25% of the E-waste in Malaysia is recycled while the remaining are not properly recycled, which can be worth about RM3 billion for its precious metals (Andeobu et al., 2021; Lim, 2019).

Under the auspices of the Asia E-waste Project, the first-ever e-waste inventory was conducted from 2007 to 2009.(Department of Environment Malaysia, 2008). The inventory offered tentative estimates on e-waste quantities generated in 2015, which were projected to reach over 900,000 tonnes from the Big 6 goods, including televisions, washing machines, refrigerators, air conditioners, computers, and mobile phones.(Honda et al., 2016). The estimation increased to more than 1 million tons in 2020. However, the figures estimate a per capita waste creation of more than 30 kg per inhabitant, which is absurdly high; Hong Kong has the highest per capita e-waste generation in Asia, at 22 kg per person. This somehow shows that there was no exact value for E-waste generated being recorded in Malaysia, which is also a gap found in this research where there is a poor statistical evaluation on Malaysian E-waste. Nevertheless, it is a global awareness that the world E-waste will increase over time and in the future (Ismail and Hanafiah, 2021).

2.3. Existing policies and guidelines

Ministry of Natural Resources and Environment (NRE) is responsible for E-waste legislation in Malaysia. E-waste management is regulated under the Environmental Schedule Waste Regulations 2005, while E-waste itself is listed in the First Schedule under the code SW110 (Department of Environment, 2005) that include printed circuit board, electronic components, and wires (Department of Environment Malaysia, 2008; Forti et al., 2018). Disposal, treatment, and recovery of scheduled wastes should be made at premises prescribed by the Environmental Quality (Prescribed Premises) (Scheduled Wastes Treatment and Disposal Facilities) Or-der 1989 [P.U. (A) 140/1989] or on-site treatment facilities.

Every generation of E-waste must be discarded formally through either authorised collection centers or retailers who provide the collection points. It is strictly prohibited to discard E-waste through informal sectors due to an unclear way of processing the E-waste and could be unsafe to the environment. Therefore, household E-waste can only be obtained by accredited or authorised collectors who have met the DOE's and other relevant agencies' standards and criteria. Local governments, concessionaire companies, non-governmental organisations (NGOs), charity organisations, retailers or dealers, private collectors, and authorised ad-hoc campaigns such as schools, universities, institutions, and community groups are among the various types of collectors (Department of Environment Malaysia, 2020). For example, several companies have taken the initiative to organise a Take-Back Program (TBP) both in the effort to reduce the amount of E-waste being disposed of in landfills and to increase awareness among the communities on E-waste management (Ahirwar and Tripathi, 2021; Forti et al., 2018). In addition, the Extended Producer Responsibility (EPR) is applied in several areas on as voluntary basis.

There were 129 E-waste facilities in Malaysia as of July 2016, covering 97 partial recovery cases. Thirty-two full-recovery e-waste facilities E-waste disposal facilities. The partial recovery means segregation physically or manually for further processing while the full recovery facilities are able to process the E-wastes to recover the precious metals (BCRC-SEA Semarang, 2016). The list of recovery facilities is listed on the DOE website for public reference, including the collection points where they were listed and existed in every state of the Peninsular of Malaysia.

Aside from that, in April 2018, the Department of Environment (DoE) released a report on the management of household E-waste in Malaysia. They demonstrated the use of the Manifest system to report data from collectors, transporters, and recycling facilities, as well as data from manufacturers and importers and information from E-waste recycling facilities (Yamashita, 2018). The manifest system describes a series of permanent and linked documents where the material is tracked in every phase involved. DOE presented how all parties would be involved in making reports and synchronising with each other, still with several challenges that they have yet to overcome. A manifest system called "Electronic Scheduled Waste Information System (e-SWIS)" was introduced to control the E-waste production from electrical and electronic manufacturing industries (Department of environment, 2018). In terms of domestic E-waste, DOE is still in the process of building a proper management system and framework to govern important organisations along with the entire flow of residential E-waste management.

Malaysia is currently collaborating with the Japan International Cooperation Agency (JICA) Technical Expert to execute the Project for Development of Mechanism for Household E-waste Management in an effort to implement a legal structure and organisational mechanism. As of March 2020, the drafted Environmental Quality (Household Scheduled Waste) Regulation is under the review by Attorney General's Chamber of Malaysia (AGC Malaysia), which covers the Big 6 products (Advance MP Technology, 2015; Enlighted Inc, 2016). The government is proposing a change to a law that mandates consumers to send in certain unwanted electrical and electronic items to licensed places that handle E-waste.

2.4. IoT emergence towards future E-waste generation

In 2016, 54 million tonnes (49 million metric tonnes) of discarded Electrical and Electronic (EE) products were generated. According to the Solving the E-waste Problem (StEP), the globe will produce approximately 33% more E-waste, or 72 million tonnes (65 million metric tonnes) by 2017. Asia is one of the most important markets for EE industries, accounting for roughly half of global sales by volume and producing the most E-waste. Similarly, waste from abandoned EE gadgets and equipment has reached crisis proportions in East Asia, posing a significant hazard to health and the environment. In the last five years, electronic waste has climbed by approximately two-thirds on average, totalling 12.3 million tonnes in 2015 (Wright, 2017).

E-waste itself is known for its causes to the environment when it is disposed of arbitrarily due to the hazardous chemicals it contains. Electrical and electronic items may contain lead, cadmium, mercury and other harmful substance, which, when leached into the water supply or soil, could cause severe problems from pollution (Bel et al., 2019; Seah, 2018) to human health issues to even death. Furthermore, interactive devices or mobile technologies often use batteries, which causes another issue: battery waste. The technologies include hearing aids, toys, electric vehicles, smartphones, etc. Batteries can contain at least one out of the following nine metals such as lithium, cobalt, cadmium, lead, zinc, manganese, nickel, silver, and mercury (Bel et al., 2019). The UN mentioned that the device collection remains critical and, as with all components, will be important for the increased collection of batteries for recycling (Bel et al., 2019).

As more and more objects are becoming computerised and digitised, and thus more will wind up in landfills, the rise of IoT is seen as an increasing culprit in losing the struggle against E-waste (Louchez and Thomas, 2014). According to the United Nations University (UNU) analysis, E-waste discharged in 2014 contained 16,500 kilotons of iron, 1900 kilotons of copper, and 300 tonnes of gold, in addition to considerable amounts of silver, aluminium, palladium, and other potentially recoverable resources. However, E-waste dumped in landfills contains

high levels of health-threatening pollutants such mercury, cadmium, chromium, and ozone-depleting substances (United Nation University, 2015). As a result, another source of concern is the hazardous compounds utilised in the manufacture of IoT devices and sensors, which will have a substantial environmental impact once they have reached their end of life (United Nation University, 2015).

Aside from that, urbanisation will continue to rise, with a projected two-thirds of the world's population living in cities by 2050, contributing to a 70% increase in Greenhouse Gas (GhG) emissions and energy use (U.S. Energy Information Administration, 2016). Furthermore, the accelerating expansion of IoT has the potential to result in an infinite increase in energy consumption (Circle ID Reporter, 2016). As a result, the internet consumes a considerable amount of world electrical supply, which is a big challenge in global attempts to minimise carbon emissions. In addition, the total energy required to build and produce hundreds of thousands of new IoT devices has skyrocketed (Advance MP Technology, 2015; Enlighted Inc, 2016; Gardiner, 2014; Louchez and Thomas, 2014; Vallathan et al., 2021; Yadav et al., 2021; Balamurugan et al., 2022).

Furthermore, while many components that go into goods are made entirely by other companies, corporations that make and sell electronics frequently underestimate the amount of energy they require (Finley, 2014). IoT necessitates the use of massive data centers to analyze, store, and fulfil IoT demands. Other concerns include the power usage by servers to connect networked sensors and devices, including the emission of co2 released by servers and data centers themselves.

3. Theory and model adoption

The Integrated Sustainable Waste Management (ISWM) presented in Fig. 1 was developed in the 1980s and has been expanded and modified and applied in a lot of national contexts (Ignatuschtschenko, 2018). ISWM is an integrated model that recognise the relationship between the dimensions and overlaps between various processes and other economic subsystems (Willard, 2010).

The holistic approach provides a more comprehensive approach to waste management planning and processes, resulting in constructing a more sustainable system (Ignatuschtschenko, 2018). The ISWM consists of three main dimensions that correspond to three questions; (1) Who should be involved? (2) What should be done? and (3) How should it be done? Hence concluding as the dimensions of Stakeholders, Elements, and Aspects, respectively. The Integrated Sustainable Waste Management (ISWM) (Ignatuschtschenko, 2018) is adopted from the United Nations Settlements Programme 2010. The dimensions include "Waste System Elements," "Stakeholders," and "Aspects," in which the model generally stipulates the main elements to be addressed for managing waste sustainably.

The ISWM was adopted in this study because of its comprehensiveness. The Three Pillars Model is regarded as the most widely used sustainable development model. The model consists of three dimensions that are viewed as separate entities. This has indeed become a limitation of the model. Researchers have debated that separating human capital and environmental capital is irrelevant because the majority of the resources used by humans come from nature in the form of ecosystem services. Stavins et al. (2003) suggested that the pillars should be interlink because the consumption of resources will vary because of behaviour, technology, and availability. Another limitation of the Three Pillars Model is the elements for each for the pillar as there is a lack of consensus about the elements under each pillar (Kates et al., 2005). This is further supported by the Green Theory (Costanza et al., 1997) which stated that it is impossible to separate human development from environmental development as majority of resources that human use come from nature in the form of ecosystem (Costanza et al., 1997). Based on the Green Theory and the limitation of the Three Pillars Model, it is evident that a sustainable development theory should have interlinked dimensions and that sustainability is achieved through the

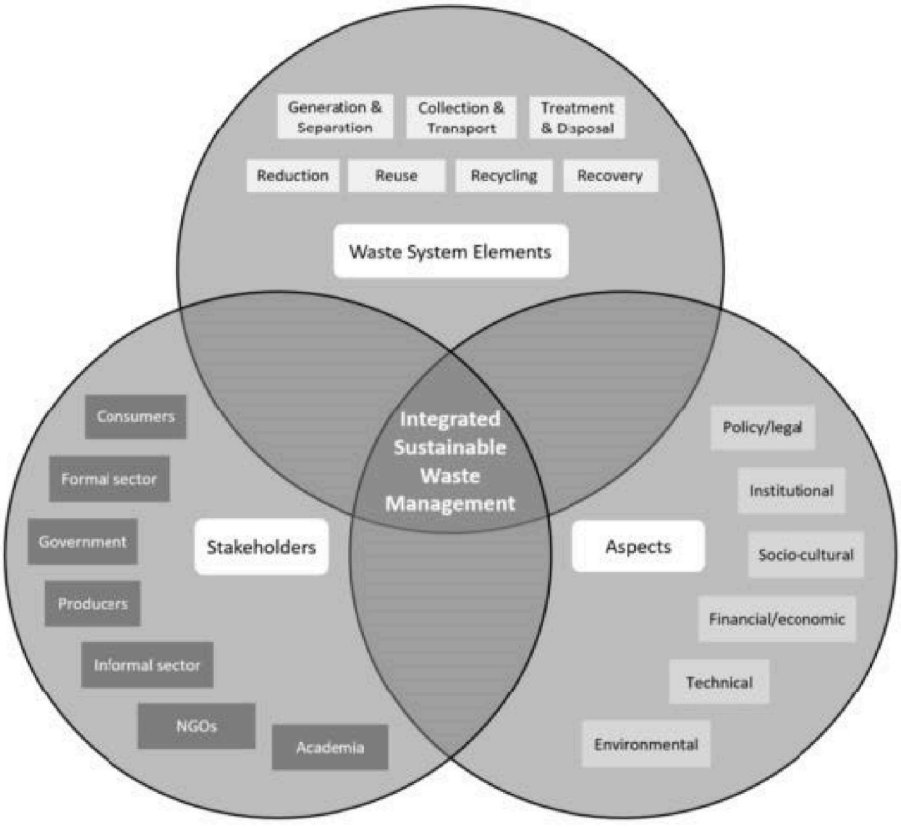


Fig. 1. ISWM model adapted from (Ignatuschtschenko, 2018; UN-Habitat, 2010) and (Klundert et al., 2001).

interdependency of all dimensions. The dimensions in ISWM are interrelated and connected. Based on the ISWM, a sustainable waste management can only be achieved when Stakeholders, Waste System Elements, and Aspects dimensions are taken into consideration in the development of any waste system management whilst focusing on the interrelation between elements within the dimensions.

4. Methodology

This study adopts a multiple case study research approach, which is particularly suited to exploratory studies (Yin, 2003). Rather than factors or causes, participants' experiences and the context of activities are critical for comprehending intricate, temporal processes (why and how of a phenomenon) (what)Rather than factors or causes, participants' experiences and the context of activities are critical for comprehending intricate, temporal processes (why and how of a phenomenon) (what) (Bhattacherjee et al., 2012). By using a multiple-case study, each instance serves a specific purpose within the overall scope of the investigation. Three examples were chosen to accomplish a literal replication in this study, and the case study replications were adjusted to provide a robust finding.

The research design is based on the work of (Yin, 2003). The research activities consist of 5 phases namely Problem Formulation, Case Study Preparation, Data Collection, Data Analysis and Guideline Development and Validation.

4.1. Phase 1: Problem Formulation

Phase 1 is about the formulation of the problem statement, which includes a review of the literature as well as research gaps, research questions, and research objectives. The content analysis on the secondary data is gathered from annual reports, sustainability reports, environmental policies, IoT and e-waste policies, newsletters, and webpages. The output of Phase 1 is dimensions and its proposed elements for the Integrated Sustainable E-waste Model (ISWM) which are based on sustainable theories and models from the secondary data. The ISWM act as a guide for the study and is adapted accordingly based on findings throughout the research as shown in Fig. 1 with its dimensions and proposed elements.

4.2. Phase 2: Case Study Preparation

Phase 2 concerns with preparing the case studies. The activities in Phase 2 were conducted from September to December 2018. To prepare for the case studies, interview questions were drafted. The ISWM is the foundation that guides the development of the data collection instrument thus, the interview questions were developed according to the dimensions of ISWM. The questions for the Stakeholders dimension focus on organization and individual-related questions. The questions concern the initiatives by the government agencies and e-waste collectors and other stakeholders involved in the e-waste management process. For the Waste System Elements dimension, the question relates to the participant's insights on e-waste management process. The Aspects elements focus into the policies and regulations of managing e-waste. The questions relate to the respondent's opinion on the existing policies and regulations, enforcement, and areas of improvement.

The development of the instrument is aligned with the objective of the study. While the household IoT e-waste guideline is to be used by policymakers and regulators therefore, it is crucial that all stakeholders are included in the research. The stakeholders are household e-waste collectors, industry specialists and IT consultants. These stakeholders become the cases for this study. As a result, the cases are as follows: (1) Household E-waste Collectors; (2) Industry specialists; and (3) IT consultants. From these three cases, the participants were identified and contacted. The participants for each case will be guided through same set of questions but with different context. For example, e-waste collectors will respond to the question from an e-waste collector's perspective. Using the same set of interview questions for the three case is an attempt to reduce bias and increase certainty of the research findings as the data from a case is triangulated with data from another case (Fusch et al., 2018).

The participants feedback and insights from the interviews contribute to the development of the guideline. This justification of using interviews as the main instrument because it helps the researcher to obtain rich and insightful opinions and feedback on the issues and challenges in IoT household e-waste management from the participants. The participants come from various backgrounds thus providing the researcher with insights from various perspectives. This is important in the development of the guideline as the intention of the study is to produce a guideline that is holistic and integrated to all stakeholders.

To test the suitability of the interview questions, a preliminary study was conducted. Interview sessions were conducted with IT consultants that provide insights on IoT and its impact on sustainability, e-waste collectors on how household e-waste are being handled and government agencies that have been involved in e-waste initiatives. The outcome of the preliminary study has provided a better insight into the existing situation on e-waste management, initiatives, and the stakeholders. The preliminary study can be regarded as a pilot study. This allows for adjustments in terms of research activities and data collections.

4.3. Phase 3: data collection

In Phase 3, the interview sessions were conducted with participants from the three cases. An interview protocol was developed to guide the interview sessions. The interview begins with a brief overview of the project and the purpose of the interview sessions and the researcher's expectations. A total of six participants, two from each case, participated in the interview sessions. The sessions are conducted either through a face-to-face meeting or online platform. The description of the participants is presented in Table 1.

The selection of the participant is based on their level of knowledge and experience on IoT and e-waste management in Malaysia. With their knowledge and experience, the participants can provide insights on the issues and challenges of household IoT e-waste management in Malaysia. Because of the three cases, each participant comes from a different background giving the researchers with different perspectives which is crucial in providing the study with a holistic and integrated perspective.

The interview sessions were conducted from April to September 2019. The interview sessions focus on the participant's perspectives and understandings on IoT and E-waste management in households rather than representing their companies. The interview addressed a variety of topics, including IoT devices (hardware), environmental benefits and risks associated with e-waste, as well as concerns and obstacles they face managing household e-waste as a customer.

There are eighteen questions that are used as a guide for the semi-structured interview. The participants are free to discuss and provide in-depth insights on the issues of IoT e-waste management according to their own perspectives as an e-waste collector, industry specialist or IoT consultant. During the interview sessions, the participants were encouraged to provide in-depth descriptions and insights of IoT and current E-waste management based on their knowledge and experience in managing e-wastes. The researcher framed the questions in such a way that it was not seen as hinting to the participants to agree or disagree with the researcher. This is important to reduce biasness in the participant's response. The eighteen open-ended questions are categorized into the three main components of IWSM that are Stakeholders, Waste System Elements and Aspects. Table 2 shows a sample of questions for each of components of the ISWM.

All interviews are conducted in English. After each interview, the transcript of the interviews, observation notes and memos are digitally documented with consent, and then transcribed verbatim into Atlas. ti

Table 1
Description of participants.

Case	Background group	ID	Participant	Position	Background description	Interview Setting
1	E-waste collectors	C1: P1	Participant 1	Special Projects Manager	Waste collector	Physical meeting
		C1: P2	Participant 2	Founder	E-waste collector	Physical meeting
2	Industry experts	C2: P3	Participant 3	Chairman	IoT services provider	Tele conference via Skype
		C2: P4	Participant 4	Engineering Manager	Malaysia digital maker marketplace provide products for robotics and electronic projects	Tele conference via Skype
3	Consultants	C3: P5	Participant 5	Speaker, Consultant	An international development organization	Tele conference via Skype
		C3: P6	Participant 6	Solution Consultant	Solution Consultant for ICT	Tele conference via Skype

for analysis. The findings of the analysis were evaluated and considered for the next interview session thus resulting in adjustments to the interview method as well as any issues raised during the previous interview session.

The qualitative data analysis began with a transcribed interview text. First, the interview texts are read and re-read to understand and gain a general understanding of the matter being discussed by the participants. The texts are then divided into smaller parts which are called "meaning units". It is then condensed further into more understandable and simpler words without changing the core meaning of the statements. The condensed meaning units are then labelled with codes and grouped into categories.

4.4. Phase 4: data coding and analysis

The data is analyzed in two stages: (1) within-case analysis and (2) cross-case analysis. Within-case data analysis looks into different approaches through each case setting and looks for patterns to justify the problem identification model. A cross-case analysis was used to determine common characteristics and patterns across different case settings, which are then utilised to verify or refine the core theory into a more comprehensive and generalizable theory.

Atlas.ti, a computer-assisted qualitative data analysis software, is used to document, extract, and arrange data acquired during the actual data collection process. The use of Atlas. ti allows the researcher to analyze the data rigorously and systematically. This reduces biasness and increases transparency (Houghton et al., 2017).

Table 2
Sample interview questions.

Components of IWSM	Sample Interview Questions
Organization (Stakeholders)	• How do you and your organization manage/dispose small electronic components (sensors, motherboard, etc.) in electrical devices that has been called as electronic waste (E-waste)? • Do you collaborate with other organization in any e-waste management initiatives and if yes, name a few and in what way do you collaborate with them? What are your opinions on those collaborations?
IoT E-waste (Waste System Elements	• How do you see the e-waste from IoT devices as different from e-waste produced from other electrical/electronic devices in terms of management and disposal? • What is your opinion on the management and disposal of household IoT device and industrial IoT device?
Policies and Regulations (Aspects)	• What do you think of those policies and regulations in assisting stakeholders to manage and dispose IoT household e-waste? • What do you think that needs to be improvements that can be done to those existing policies and regulations?

Participants' quotes from the transcript are open coded accordingly. During data analysis, the coding was used to identify evidence that are contradicting. Identifying contradicting evidence provide the researcher with an opportunity to come to terms with confirmatory bias (Skjott Linneberg and Korsgaard, 2019). To ensure that the confirmatory bias is further reduced, the coding is analyzed within case and cross case. For within case analysis, the coding is shown to other peers to get their feedback. For cross case analysis, the sets of coding are compared if there exists any contradicting evidence, trends, or patterns.

The quotations from the interview transcript are open coded with proper code phrases which were guided by the preliminary data collected. These codes are then categorized according to the elements of Sustainable Household IoT E-waste Management model and further grouped into themes of dimensions. The abstraction of codes is presented in Table 3.

Every code is a set of a code ID that is applied to distinct quotations and is used as a reference to the quotations listed in the report as "[Case number: Participant Number: Quote order]". Codes are then being categorized based on elements mentioned in the model. These data are then exported and reported in Microsoft Word Document before it is applied for the Sustainable Household IoT E-waste guideline development. The sample coding is illustrated in Fig. 2, where a participant was asked on a stakeholder's responsibility for managing E-waste. The right side of the figure displays all the codes assigned to selected quotations (on the left side).

Every code consists of code ID assigned to specific quotation. Fig. 3 illustrates the "ID", quotations being assigned to the codes (Name), and the word number from beginning to end of quotations. In the ID column, the ID was displayed as "Document number: Quote order". The ID is used as reference to the quotations being cited in the following chapter as "[Case number: Participant Number: Quote order]".

Codes are then being categorized into elements taken from the model. Fig. 4 shows the categorization of codes in the code group's panel. The example shows the codes being categorized under the dimension "Stakeholders".

Fig. 5 further illustrates the data abstractions from quotations to finding the theme. The figure shows an abstraction of Government as one of the stakeholders involved in the management of E-waste in Malaysia as per interviewed with experienced participants.

4.5. Phase 5: guideline development and validation

From the data analysis, literature review and best practices from other countries, the guideline for a sustainable household IoT e-waste management is developed. Next, the guideline is sent for expert review validation. The validation ensures that the guideline can provide the government agencies and policy makers with a clear direction in managing IoT e-waste (Eurostat, 2017).

In this study, several experts were chosen for their credibility in the research topic area. In the questionnaire, the experts were asked about

Table 3
Abstraction table.

Open Code	Category	Theme
[Stakeholder][Consumer] [Organization][Collaboration]	Consumers	Stakeholders
[Stakeholder][Formal Sector] [Organization][Collaboration]	Formal Sectors	
[Stakeholder][Government] [Organization][Collaboration]	Government	
[Stakeholder][NGO] [Organization][Collaboration]	NGO	
[Stakeholder][Producers]	Producers	
[Mgmt][E-waste][Household] [Generation&Separation]	Generation & Separation	Waste System Elements
[Management][EE][E-waste] [Household]		
[Mgmt][E-waste][Household] [Collection&Transport]	Collection & Transport	
[Management][EE][E-waste] [Household]		
[Organization][Operation]		
[Organization][Collaboration]		
[Mgmt][E-waste][Household] [Treatment&Disposal]	Treatment & Disposal	
[Management][EE][E-waste] [Household]		
[Organization][Operation]		
[Mgmt][E-waste][Household] [Reduction][Monitoring][IoT]	Reduction	
[Mgmt][E-waste][Household][Reuse]	Reuse	
[Management][EE][E-waste] [Household]		
[Mgmt][E-waste][Household] [Recycling]	Recycling	
[Mgmt][E-waste][Household] [Recovery]	Recovery	
[Organization][Operation]		
[Organization][Collaboration]		
[Policy and guideline][E-waste]	Policy/Legal	Aspects
[Policy and guideline][E-waste] [Household][Lack]		
[Policy and Guideline][E-waste] [Opinion]		
[Policy and Guideline][IoT E-waste] [Opinion]		
[Waste System Elements]		
[Stakeholders] [Societal contribution][Consumer] [Aspects][Institutional]	Institutional Socio-cultural	
[Aspects][Financial][Support][E-waste] [Management]	Financial/ Economic	
[Neg. impact][EE][E-waste]	Environmental	
[Neg. impact][IoT][E-waste]		
[Neg. impact][IoT][E-waste][5–10 years]		
[Neg. impact][IoT][Environment][5–10 years]		
[Pos. Impact][IoT][E-waste]		
[Statistics][E-waste]		

the general presentation of guidelines, information deliverance, and the effectiveness of the information delivered. Corrections and adjustments are made upon receiving feedback and comments from the experts. Finally, the research is reported indicating the research completion.

5. Result and discussions

5.1. Guideline development

5.1.1. Recognising challenges and proposing solutions

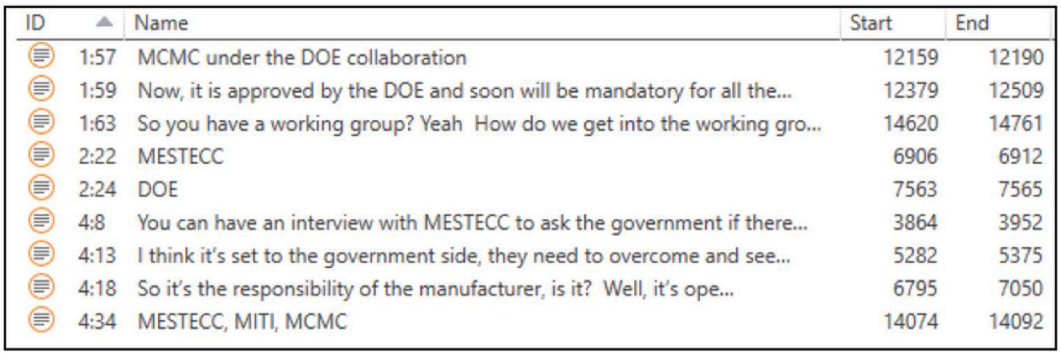
Several issues and challenges faced by consumers in managing their household E-waste are identified from the data collection. With the adaptation of the model developed, data are categorized and analyzed based on the themes projected from the model. Solutions are then proposed for developing guideline content later in the study. The summary of findings is presented in Table 4.

A guideline is developed called the Sustainable IoT E-waste Management Household Guideline, which delivers suggestions for managing household IoT E-waste sustainably. This guideline aims to propose suggestions for policymakers and other relevant agencies in Malaysia in enforcing a different approach for Household E-waste management for wastes from used household IoT products, which is part of the near future environmental issue. On top of that, some suggestions might be useful in finding solutions for the challenges found in the previous report on Collection, Storage, Handling and Transportation of Household E-waste in Malaysia.

The guideline focuses on the selected stakeholders, including the Government, generators, or consumers of IoT, formal sectors (waste facilities), collectors including Non-Governmental Organization (NGOs) and private waste facilities, and manufacturers and producers of IoT devices. Thus, from the findings, suggestions on the roles and responsibilities of each party are described in this guideline, aiming to provide an eye-opener to all agencies involved in household IoT E-waste management. This guideline helps policymakers strategise on the design, development, and implementation of IoT projects to achieve the national goals of (1) reducing carbon emissions intensity by 45 percent by 2030 and (2) creating a conducive IoT environment.

5.1.2. Addressing solutions into guideline

DOE has drafted the Environmental Quality (Household Scheduled Waste) Regulation and is under review by AGC Malaysia. The items covered under the project are the Big 6 products, including television sets, personal computers, mobile phones, refrigerators, air conditioners and washing machines (Honda et al., 2016; Leoi, 2019; Rautela et al., 2021). However, despite the six specific household items being regulated, there is a lack of specific interactive devices of IoT mentioned other than mobile phones. According to the study, the participants mentioned several IoT devices used in homes, including smart home appliances, intelligent transportations, wearable health, monitoring



ID	Name	Start	End
1:57	MCMC under the DOE collaboration	12159	12190
1:59	Now, it is approved by the DOE and soon will be mandatory for all the...	12379	12509
1:63	So you have a working group? Yeah How do we get into the working gro...	14620	14761
2:22	MESTECC	6906	6912
2:24	DOE	7563	7565
4:8	You can have an interview with MESTECC to ask the government if there...	3864	3952
4:13	I think it's set to the government side, they need to overcome and see...	5282	5375
4:18	So it's the responsibility of the manufacturer, is it? Well, it's ope...	6795	7050
4:34	MESTECC, MITI, MCMC	14074	14092

Fig. 2. Open coding a quotation from an interview script.

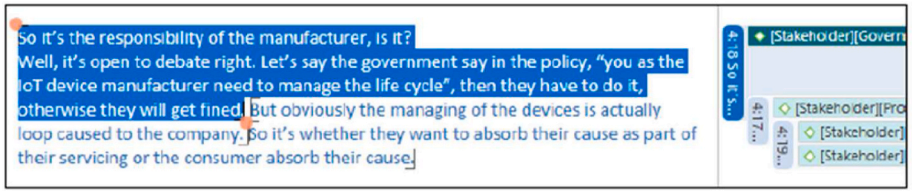


Fig. 3. Displaying code ID.

Fig. 4. Code groups of "Stakeholders" element.

systems, smartphones, and smart entertainment devices (Andeobu et al., 2021; Rautela et al., 2021).

From the numerous examples of IoT devices used in homes, these items were identified as "Consumer IoT" and were explicitly identified as follows:

- Smartphones and watches
- Smart home appliances
- Motion detection, curtain control, light control, temperature control, air controller control, air quality sensor, plug control, gas lock control.
- Fitness monitoring devices

Smart devices are implemented with IoT sensors. From the data, it is unnecessary to have a smart home to have smart devices. Therefore, people are beginning to use and implement smart devices into their homes without proper knowledge and awareness for managing them at the end of products' life. On top of that, it is becoming easier and cheaper to get and use electronic products in the age of technological

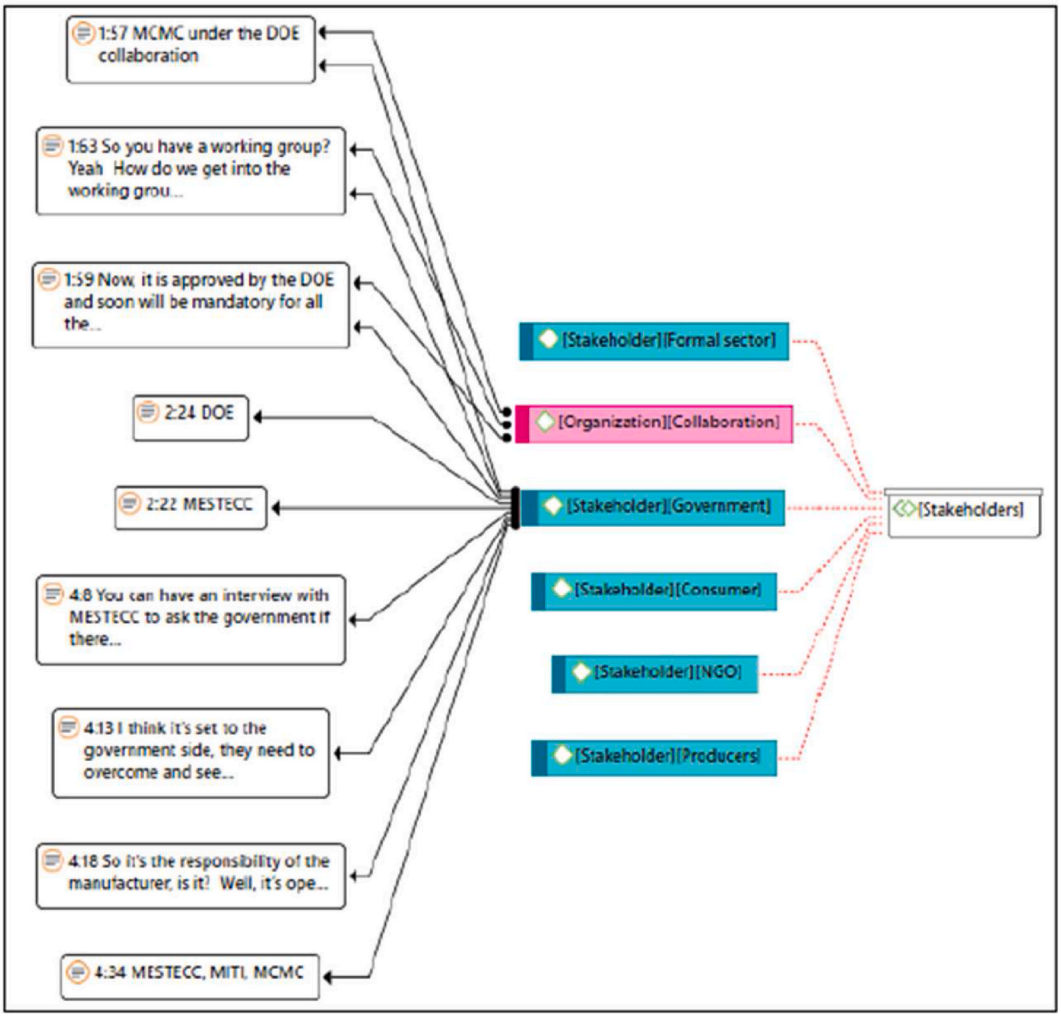


Fig. 5. Coded data network.

Table 4
Findings from data collection.

Theme	Issue/Challenge	Solutions
Stakeholders	• Household E-waste is not being treated with the same degree of urgency as Industrial E-waste • Low level of awareness • E-waste impacts on the environment • Proper management of household E-waste • Poor mentality and mind-set	• Regulate policy & guideline • Focus on the source of E-waste, which is the consumers • Training and campaign • Acknowledgement of own responsibility (all stakeholders) • Word of mouth • Awareness by manufacturers/producers on EPR • Change of mind-set • Early education
Waste System Elements	• Throw and purchase new once the gadget is broken with minimal damage • Throw E-waste with other waste • Burdensome to some individuals since finding the collection centers need "effort". • Consumers have taken the initiative to proper manage E-waste	• 3R practices • Minimise the use of unnecessary gadgets • Creative approach • Rewarding system • Collection door-to-door • Creatively provide collection bins, and • Provide easy access to E-waste collection bins (preferably in housing area)
Aspects	• EPR implemented on a voluntary basis • No regulation on household E-waste	• Companies should be responsible for their products (EPR) • Create a clear guideline of creative solutions for stakeholders • Regulate EPR • Provide financial assistance

development (Rulia et al., 2014). Hence, the policymaker must regulate policy handling specific kinds of household E-waste or IoT E-waste.

Apart from the targeted household IoT devices, it is also important to investigate the technical constituents and waste management. Unlike Japan, Malaysia has no structured mechanism to manage E-waste from households (Rulia et al., 2014). Stakeholders involved in Japan's E-waste management are closest to the ideal Integrated Sustainable Waste Management model where the government has successfully established a comprehensive system. Consumers, manufacturers, merchants, collectors, and recyclers all have distinct roles and duties, with a manifest system, licencing schemes, and regular monitoring to guarantee that each party performs its responsibility within the framework (Ignatuschtschenko, 2018). Thus, referring to the model developed in this study, the guideline is structured as per the following subsections where guideline contents are proposed in respective statement boxes.

5.1.3. *Actions by government*

The government plays a key and primary role as a regulator,

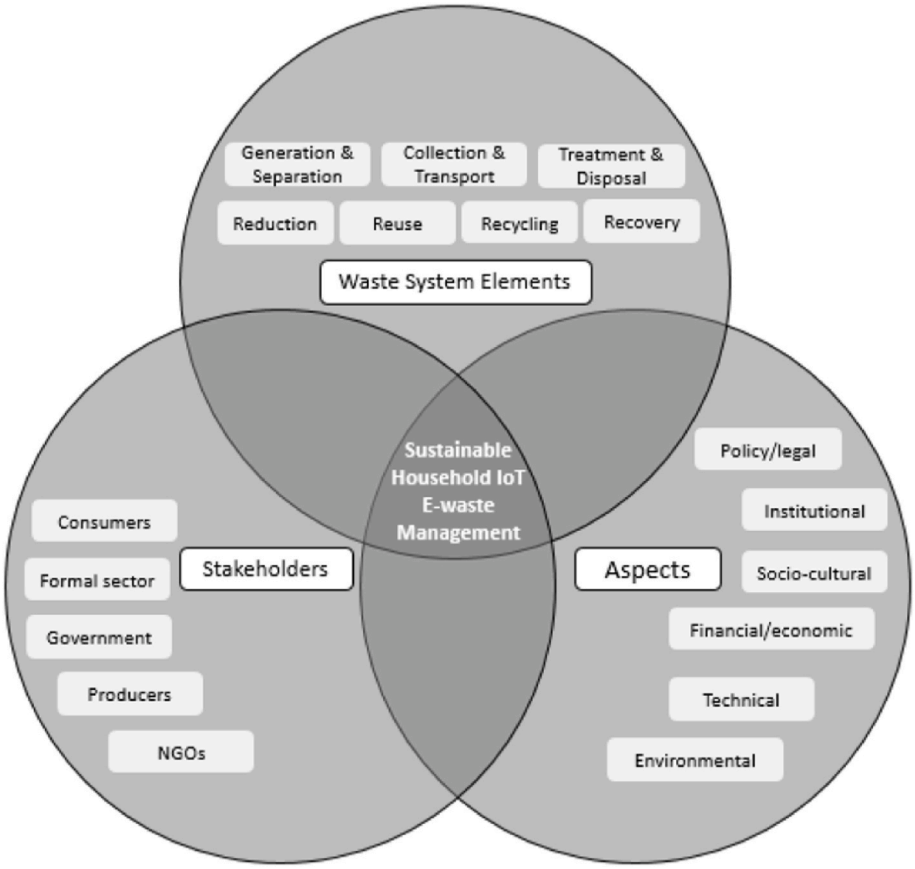


Fig. 6. Sustainable household IoT E-waste management model.

coordinator, and facilitator of E-waste management activities within many developed and developing countries, including Malaysia (Ignatuschtschenko, 2018). The governing approach to the IoT E-waste management is important for ensuring cooperation between stakeholders while realising their roles and responsibilities in the waste management system. While referring to Fig. 6, stakeholders of the Household IoT E-waste Management include the Government, E-waste generators/consumers of IoT, collectors/NGOs, formal sectors (recycling facilities), and producers/manufacturers of IT products. Thus, the government should encourage policymaking between the stakeholders involved directly in the Household IoT E-waste Management System. The paragraph below suggests an action that the government should consider.

"*Develop policy and legislation for household E-waste generators/ consumers, collectors, formal sectors which are the recycling facilities and producers and manufacturers of IT products.*"

Moreover, the government should monitor and facilitate legislation on the whole movement of IoT E-waste from the early phase of generation up to the disposal stage. This includes all necessary needs and costs of operation required by respective stakeholders in managing those wastes, such as providing funds and grants. Hence, the following action is suggested.

"*Act as the primary role to facilitate IoT E-waste management activities that focused end to end from generation to disposal."*

Referring to Table 3, there are several challenges when it comes to consumers or generators of IoT. According to the data collected, numerous collection bins are made available in public places as well as other services offered to approach the consumers, such as delivery services, cashback and rewarding systems by NGOs and private collection companies. Albeit several efforts have been made, awareness has been a greater problem in solving waste-related matters. The issue might not be the consumers themselves, but the approach that has been taken should meet the consumers' wants.

The data found that consumers are fully aware of the existing waste recycling facilities in Malaysia and the importance of recycling household E-wastes. However, participants in Case 1 who are experienced in handling E-waste mentioned that consumers prefer to just throw them along with other waste from their homes or purchase a new one due to a more convenient and less effort to get rid of the E-wastes or fixing the broken items. This is aligned with a survey conducted in 2014 where used electrical and electronic products are either kept, thrown, reused, recycled or returned to respective manufacturers by consumers in Malaysia. However, among all efforts, the consumers preferred the least on returning the items to the manufacturers and recycling centers respectively (Ismail and Hanafiah, 2021; Rulia et al., 2014). Despite the awareness of the importance of recycling those E-wastes, consumers tend to seek the least effort they can invest in.

Another issue of managing E-waste by consumers is keeping a large amount of electrical and electronic gadgets at home. According to an inventory survey under the aegis of the Asia E-waste Project, reasons for the act include the reluctance to dispose of high price gadgets and the behaviour of waiting for scrap collectors to buy their E-waste, rather than them having to pay people to collect it (Honda et al., 2016). That being said, numbers of informal collection networks are still widespread in Malaysia, which is most known by Malaysian as "the old newspapermen" despite the existence of licensed E-waste collection companies. From the research findings, numbers of NGOs and formal E-waste collection companies offer rewards to the consumers who send used electrical and electrical gadgets to them at a reasonable price rather than scrap rate. However, consumers' lack of awareness of the rewarding practices by collection companies leads most consumers to seek an easier solution, as mentioned earlier.

Thus, several solutions such as providing the nearest possible waste bins specifically for E-waste to the consumers, introducing a formal collection targeting specific wastes according to days and promoting rewarding initiatives widely may tackle the issue. Therefore, the guideline statement is presented in the paragraph below.

- "*Providing specific bins for E-waste and IoT E-waste in houses or housing areas in par with the existing bins for collecting municipal wastes with colour coded bins.*"
- "*Introducing colour-coded waste collectors and trucks to pick up wastes from generators according to colour-coded waste bins by schedule. (Example: Blue trucks for blue bins (paper) on Tuesday, green trucks for green bins (municipal waste) on Saturday etc.).*"
- *"Promote rewarding initiatives for society who are involved in recycling efforts. (Example: Discount groceries coupons, cashback alternatives etc.).*"

On top of that, another concern of creating awareness on proper waste management is early age education. All participants from the interviews suggested that education plays a vital role in developing awareness and the common sense of wanting to reduce waste from ending up in landfills. Moreover, awareness of the hazards of E-waste is very important to practice recycling behaviour among society (Rulia et al., 2014). Therefore, promoting awareness and providing necessary education on proper IoT E-waste management is part of the important responsibilities of the authorities, as per stated in the following paragraph.

- "*Promote household IoT E-waste disposal to proper channels such as campaigns, advertisements, educational videos for schools and institutions, and community services.*"
- *"Conduct awareness and educational programs on sustainable waste management for society through channels mentioned above."*

Another important mentioned point of E-waste management is EPR or take-back system. Lindhqvist first proposed EPR in 1992, where he stated that producers should extend their responsibility to the entire life of a product, including production, sale, reclaiming, and disposal of the end-of-life product (Yin, 2003). However, Malaysia has not made the EPR or take-back system mandatory to producers or manufacturers of IT, but rather on a voluntary basis. Thus, the government should really look into regulating a policy on making EPR obligatory for IT manufacturers.

"Enforcing the Take Back Program (TBP) and Extended Producer Responsibility (EPR) for manufacturers and producers of IT products."

Apart from that, from the data, DOE projected estimation of more than 1.1 million metric tons of E-waste being produced in the year 2020 (Ab Rahman, 2018). However, this figure suggests a per capita waste generation of more than 30kg/inhabitant, which is unrealistically high comparatively to the highest per capita E-waste generation in Asia is Hong Kong at 22 kg/inhabitant. Furthermore, a more recent estimation by United Nations University (UNU) provided an E-waste arising estimation in Malaysia of approximately 90,000 tons per year from the Big 6 products (Honda et al., 2016). However, with no specific data being recorded for household E-waste generation in the Department of Statistics (DoS) Malaysia's website, this may conclude that there is no exact value for E-waste generated being recorded in Malaysia although estimated by DOE and UNU. Nevertheless, it is a global awareness that the world E-waste is and will increase over time and in the future (Balde et al., 2017; Bel et al., 2019; OECD, 2018). Therefore, there should be a system to monitor the movement of waste from its generation to the disposal stage, as stated in the following paragraph.

"*Monitor the household IoT E-waste movement and statistics (Department of Statistics Malaysia (DoS)). [Proposed monitoring system is presented in Fig. 3].*"

The system aims to provide a sustainable IoT E-waste management for households and the stakeholders involved in managing those E-

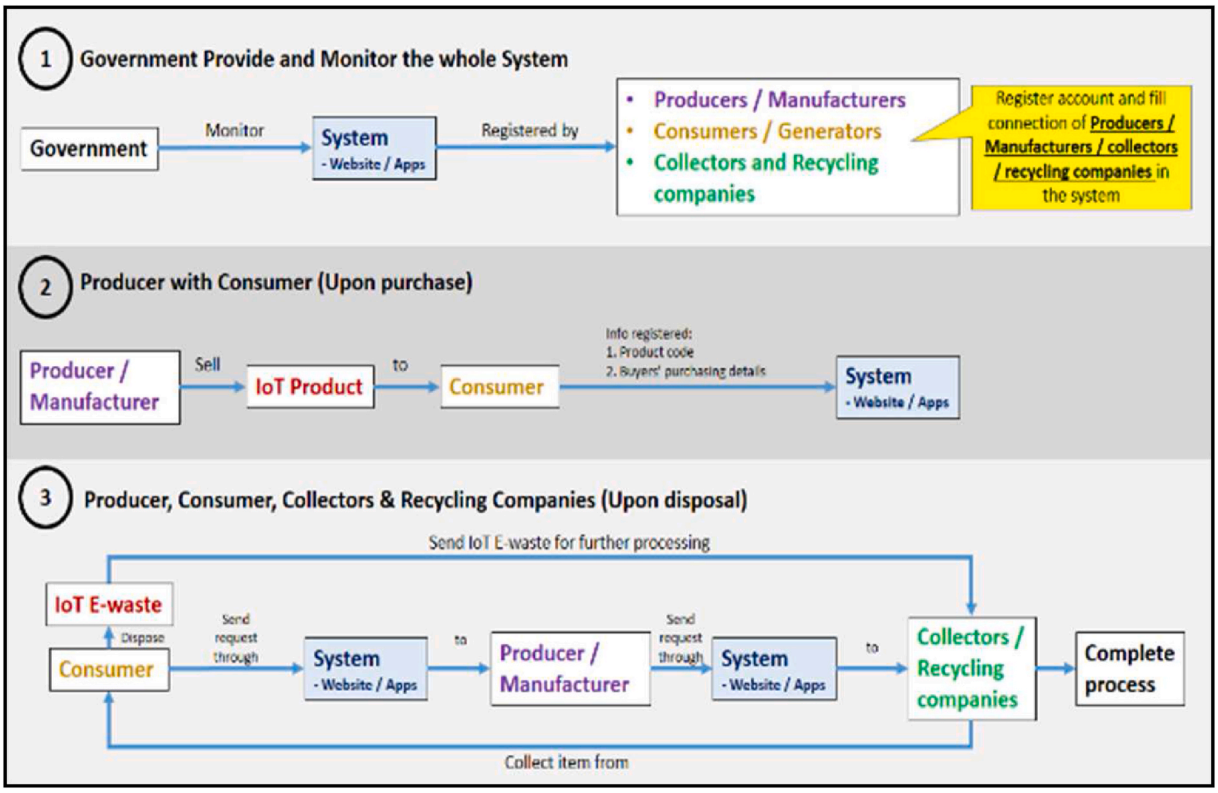


Fig. 7. Sustainable household IoT E-waste monitoring system.

waste. Those involved are the government, generators/consumers, E-waste collectors and transporters, formal waste facilities, and manufacturers/producers. In addition, the government is entitled to monitor the movement of E-waste through this system, where it connects and stores the record of the movement of IT products from the day it was produced until the day it is disposed of.

Stakeholders are required to register an account in the system as well as necessary information and details about their organization. Producers or manufacturers are required to register the product information (Example: ID, buyers' detail) in the system upon selling and purchasing products. All information about the product purchases is made available in the system for the consumers to refer to. Once the product reaches the end of life, consumers can access the system Application for discard requests. Consumers' requests are then delivered to the manufacturers or the collection companies nearby for item pick-ups. Statuses of items are recorded in the system from the day it was purchased until the day it is disposed of. Consumers are notified when the items are safely delivered to the formal recycling facilities for further processing while all other data are stored in the system for governmental purposes.

Fig. 7 summarises the phase and process of the Sustainable Household IoT E-waste Monitoring System that could be developed as a monitoring system and may as well contribute to a better statistic count for E-waste in Malaysia.

5.1.4. Actions by generators/consumer of IoT

In the current Malaysian household E-waste flow, consumers are integrated into the formal collection and transportation of waste as a primary stakeholder whose role was recognised as the generators of household E-waste. However, there is no formal collection of E-waste from door-to-door and no structured mechanism to manage E-waste from households (Rulia et al., 2014), unlike the collection of municipal waste, which is conducted on a scheduled basis. Based on the study, it is common for consumers to dispose of E-waste together with municipal and solid wastes since it is the easiest and fastest solution to get rid of them. On top of that, according to a survey conducted in 2014, throwing away electronic products is the second-highest solution chosen by consumers after reusing them (Rulia et al., 2014).

Discarding E-waste improperly will lead to an increase in harmful substances in landfills. With the right guidance and minimal effort, the dumping of dangerous waste can be avoided tremendously. Rather than packing and throwing the E-waste together with municipal waste from the household, consumers should simply and properly pack those E-waste in separate packages or containers. Some private collection companies or NGOs provide a service to collect the E-waste directly from homes while providing containers specifically for packing the E-wastes. However, it is not widely implemented since the companies operate in certain areas. With the help from the government and cooperation from consumers, this could be a new norm in handling future Household IoT E-waste. Thus, it is the responsibility of consumers to properly pack and segregate the E-waste from other solid or municipal wastes before discarding or sending them away. Hence, the following action is suggested.

> *"Do not dismantle any household E-waste generated. If the items are dismantled, properly pack them in containers (self-provide) before discarding into bins, collection points or giving them away."*

According to the "Collection, Storage, Handling and Transportation of Household E-waste in Malaysia" report suggested by the JICA Expert Team (Yamashita, 2018), several guidelines should be implemented and abide by consumers, which include the prohibition to dismantle household E-waste generated, giving out E-waste only to authorised collectors, and be responsible on household E-waste generated (Lee Chong, 2018). Therefore, the following actions are suggested by the DOE.

- *"Give/donate/sell/discard household E-waste only to approved/authorised collectors or retailers."*
- *"Be responsible for the household E-waste generated; make sure it ends up at licensed facilities for proper treatment."*

- "*Do not discard/sell the household E-waste to unauthorised players/the informal sectors.*"

Referring to the study, it was suggested that the government provide specific colour-coded bins to indicate specific types of waste for households. Thus, consumers should dispose of the E-waste to the bins provided at the collection points in housing areas accordingly. Therefore, the following action is recommended.

"Discard the household E-waste to the provided or nearby E-waste bins that are colour coded at collection points in housing areas or public places."

Moreover, it is important to distribute and increase awareness on the proper management of household E-waste among consumers and it should be nurtured from an early age. Besides, there is a need for an educational campaign since it is essential to improve elementary education in environmental protection and resource conservation to foster the E-waste recycling behaviour from childhood (Rulia et al., 2014). These can be done through self-learning, guideline videos by policymakers either in schools or any institutional units, as well as making use of social media platforms to advertise the Sustainable IoT E-waste Management for Household.

"*Create the culture of proper waste disposals by creating awareness, starting from the younger generations through self-learning, guideline videos by policymakers for schools and institutional units, as well as advertisements on social media.*"

5.1.5. Actions by collectors/NGOs

Due to the lack of an effective system to manage E-waste from households, collection activities for E-waste have not been structured in Malaysia (Rulia et al., 2014). E-waste collection in Malaysia is handled by numerous individuals and organisations, including formal waste collection companies, informal waste collectors, private collection companies, and NGOs. Informal waste collectors put a high risk on the possibility of illegal dumping and improper ways of disposing of the E-waste. Thus, all E-waste collectors should gain approval and authorisation from DOE to operate according to rules and regulations set by the government and ensure proper handling of E-waste collected. Several guidelines for collectors have been mentioned in Malaysia's Collection, Storage, Handling and Transportation of Household E-waste as suggested by the JICA Expert Team. The guidelines are as follows:

- *"Obtain approval and authorisation from the DOE."*
- *"No dismantling of the household E-waste received/collected If the received household E-wastes were dismantled, properly store them in containers (self-provide)."*
- *"Proper storage of household E-waste received/collected, e.g., store the lithium batteries and button batteries separately in containers at dry, cool places; beware of creating mosquito breeding ground in storage area)."*
- *"Proper labelling collection/storage areas."*
- *"Deliver the collected household E-waste only to other authorised premises or licensed recycling facilities/only use authorised transporter."*
- *"Fulfill reporting requirement (refer to the requirements in Reporting Guidelines) – manifest system [Visit link at* https://www.doe.gov.my/hhew/publications/*]."*

Apart from that, collection companies are continuously finding creative ways to approach consumers, including setting up booths for collection, providing collection bins in several public areas, as well as promoting rewarding services from recycling. Collectors, including NGOs and private collection companies, should engage more with consumers not only to promote and encourage the importance of proper E-waste management but also to increase awareness among the society on the existence of collection centers that are offering rewards and other benefits for those who participate in E-waste recycling and those who willingly send electronic devices to them.

"*Engage with household E-waste generators for awareness on the importance of proper E-waste management through the system provided by the government* [Fig. 7]."

On top of that, the transporting of that E-waste was also mentioned by the expert team in the report. Thus, transporters of E-waste should abide by the rules and regulations on handling and reporting of movement of E-waste collected. The following actions are as suggested by DOE.

- *"Obtain approval/authorisation from the DOE (Registration of transport vehicles)."*
- *"Transport of collected household E-waste following all the Land Public Transport Agency (SPAD) requirements."*
- *"Fulfill transport requirements (e.g., avoid overload; make sure E-waste transported is fully covered; no temporary storage is allowed)."*
- *"No dismantling of the household E-waste is allowed."*
- *"Proper labelling at the transport vehicle."*
- *"Deliver the household E-waste only to authorised premises or licensed recyclers."*
- *"Fulfill reporting requirements (refer to Reporting Guidelines) – manifest system [Visit link at* https://www.doe.gov.my/hhew/publications/*]."*

5.1.6. Actions by formal sectors (recycling facilities)

Formal recycling facilities handle treatment and disposal of E-waste in a proper and manageable way according to the rules and regulations legislated by the government or, specifically, DOE. In addition, the government has legislated specific requirements and conditions to manage E-waste collected from all sources, including households and industries.

- "*Obtain a license from the DOE. Also, to obtain approval as collectors or transporters. Visit DoE website at https://www.doe.gov.my/hhew/for more info.*"
- *"Receive household E-waste only from authorised/approved sources."*

Apart from that, some formal recycling facilities provide collection and transportation services for households where requirements must be fulfilled. Every operation must be reported to the DOE according to the requirement.

- *"Fulfill requirements as collectors and transporters if involved in the collection and transportation activities."*
- *"Fulfill reporting requirement. Refer to the Reporting Guidelines at* https://www.doe.gov.my/hhew/publications/."

On top of that, formal recyclers should register and gain approval according to the guideline prepared by the DOE. It is to ensure eligibility in handling and processing the waste collected.

1. Eligibility
   - *"The applicant for authorisation or registration is only applicable to a company (with the registration of ROC), association or society (with the registration of ROS) as well as any government agencies (Local, State or Central)."*
   - *"Any individual or sole proprietor, who is interested or involved in the activities of collection, storage, handling and transportation of household E-waste, shall engage any registered or authorised stakeholders for carrying out the activities."*
2. Procedures
   - *"Registration procedures are per decided by DOE. Please visit the DOE website at https://www.doe.gov.my/hhew/for more info."*

5.1.7. Actions by producers/manufacturers

Producers or manufacturers of IT products are part of the main

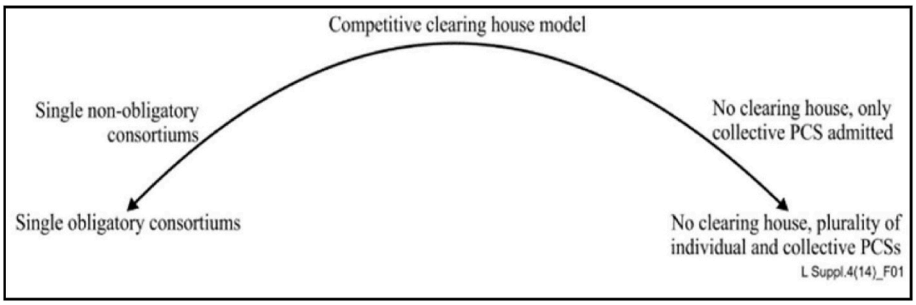


Fig. 8. Extended Producer responsibility model.

contributor towards the production of electronic devices and the nation's economy. Electronic products began to penetrate homes enormously to the extent that no household does not use any electronic products in Malaysia (Rulia et al., 2014). With the vast movement of technological development, there are no stopping people from always buying and using interactive devices, especially at home. Manufacturers are not only responsible for the production and selling of their products but also keeping track of the end-of-life of the devices. According to a participant who is also an IoT expert, IoT products should be integrated with a sensor of the life cycle which will inform the producers of its end-of-life, thus making it possible for producers to keep track and extend their responsibility to take back the broken items for proper processing, either by reuse, refurbish, recycle or disposal.

Since EPR is obligatory in Malaysia's policy, manufacturers should always look into the initiative in practising it. In Malaysia, however, numbers of manufacturers and international companies such as Dell, Nokia, and Motorola have taken the effort to organise a Take-Back Program (TBP) and offers free recycling and providing disposal facilities for users of their products (Forti et al., 2018; Rulia et al., 2014). This initiative was conducted to reduce the amount of E-waste being disposed of in landfills while increasing the awareness of the E-waste issue among society.

"*Practice Take-Back Program (TBP).*"

The International Telecommunication Union (ITU) suggested that in order to comply with EPR provisions, manufacturers must set up individual producer compliance schemes (PCSs) or by joining a collective one (Efficiency et al., 2016). An example of a system design is as illustrated in Fig. 8.

Policymakers should decide which system design suits Malaysia's condition better before drafting provisions on EPR. Then, after steps of authorisations and is deemed acceptable by all parties involved, policymakers may set up a public fund to support the promising E-waste treatment industry (Efficiency et al., 2016).

On top of that, manufacturers should also provide instructions or guidelines to their products to suggest a proper way and channel to handle the end-of-life of their products. Manufacturers should also ensure the products are designed for durability, reuse and safe recycling. The substance of concerns such as harmful materials listed in the Scheduled Waste can be substituted accordingly.

- *"Provide instruction/information on managing end-of-life of the products."*
- *"Monitor and re-ensure that products are designed for durability, reuse and safe recycling, as well as the substance of concern are substituted out."*

From this valuable and smart move, Malaysia could make it mandatory for manufacturers to practice EPR and make use of the precious metals, which can then be turned into other products or reused for future production. This will not only reduce the E-waste being dumped into landfills but may also contribute to Malaysia's economy through a circular approach (Department of Environment Malaysia, 2008), as suggested in Fig. 9.

The guideline's key contents are then listed as presented in supplementary materials.

5.1.8. *Expert review*

Experts from several backgrounds related to the field of study are given an open-ended questionnaire and a copy of the guideline draft to be reviewed. The line of experts involved a research fellow from a local university who was actively involved in projects on waste management, a founder of a waste management collection company, and a senior associate of Economics & Policy, PwC Advisory. The experts are chosen by their direct and indirect credibility and experience related to E-waste management and policy. In the questionnaire, the experts are asked about the general presentation of the guideline, information deliverance, and the effectiveness of the information delivered. The questions on the general presentation of the guideline are aimed to seek the first impression of experts toward the guideline where the opinion on the first impression and the physical appearance of the guideline are asked. As a result, the experts are convinced of the intention of the guideline while the appearance is clear and acceptable. Questions on information deliverance are intended to identify whether the writing structure is easily understood, and the diagrams are easily interpreted. Elements are deemed to be easily read and interpreted according to expert 1 and expert 2, which reflect that it is easy for guideline users to read and understand. However, some improvements are suggested while amendments are delivered accordingly.

Questions on the effectiveness of information such as the usefulness of information for the stakeholders involved, the applicability of information for future E-waste management in Malaysia, and other comments and suggestions for guideline improvement are asked in the questionnaire. An expert believed that the proposed roles are good and could be presented to policymakers for their opinion and consideration. In addition, the guidelines for other stakeholders are also considered good for future E-waste management in Malaysia. However, the practical aspect requires revision because implementing the guideline is very important for further regulation. Apart from that, the information presented will be useful for policymakers in developing policies related to household E-waste and future household E-waste management.

Furthermore, it is useful for consumers to educate them on the importance of properly managing E-waste. However, an expert suggested that the guideline will mostly be useful for E-waste collectors, NGOs and producers of IoT products as "authorised collectors status are quite new, this guideline might educate the new players and update them on the latest regulation". An expert agreed that the guideline would be useful for the policymakers in developing household E-waste related regulations.

On top of that, the expert mentioned that the guideline is applicable to a certain extent. However, some suggestions may require further study before stakeholders can implement them. She also viewed the guideline to be useful for consumers in providing awareness and education on proper E-waste management. Moreover, the guideline is useful

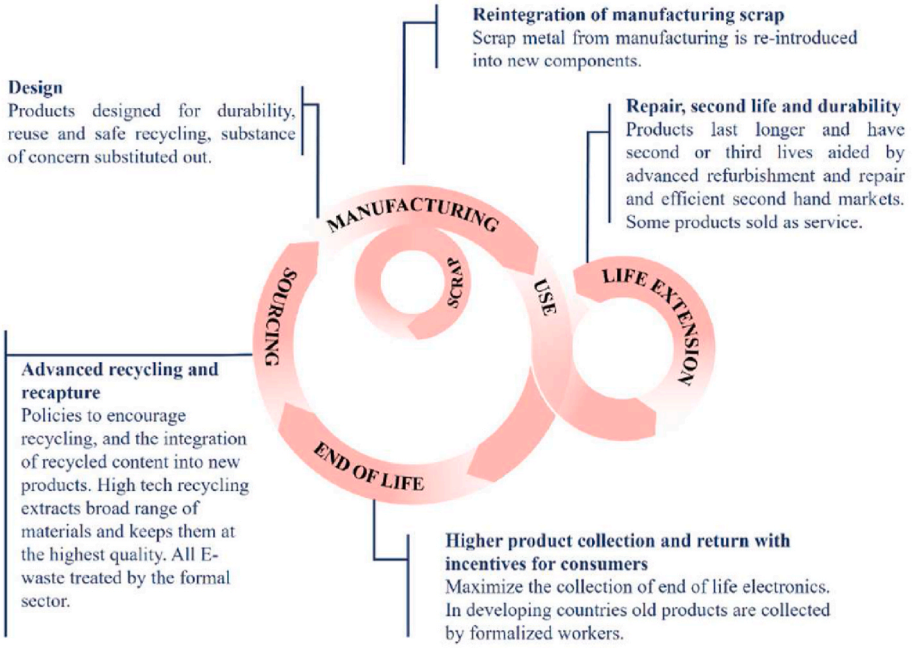


Fig. 9. A new circular vision for electronics.

to all stakeholders mentioned in the guideline, with minor changes suggested to be included in some parts of the guideline's sections.

6. Research contribution

Information Systems (IS) research on environmental sustainability is expected to position itself as more solutions-oriented and utilizing the IS knowledge in a practical and innovative ways to tackle environmental and social issues. As IS is intended to provide solutions to inform policy decisions, this research utilizes IS qualitative methods to develop the Sustainable Household IoT E-waste Management Guideline which is also the solution to face future IoT E-waste phenomena. On top of that, upon conducting an in-depth study on this research, it has opened to more IS research in the future where it has identified the main stakeholders involved in Household IoT E-waste Management system especially the consumers.

Moreover, the guideline of Sustainable IoT E-waste Management for Household can contribute to the academics, communities and society in terms of the adoption of the case study and semi-structured interviewed sessions with numerous people with diverse backgrounds, which can provide great insights in understanding the actual scenarios of household e-waste management in Malaysia. Furthermore, the guidelines contribute to the set of actions that could be taken by the governments and act as a source for references. Additionally, the model of Sustainable IoT E-waste Management for Household is developed from the adoption and adaptation of ISWM and the Overlapping Circles Model of sustainable development. Hence, it can be adopted and adapted for the same research done globally while merging with their policies and regulations. The guideline has been copyrighted under Intellectual Property Corporation of Malaysia (myIPO) with ID CRLY 2021P01429 on 16th April 2021.

7. Way forward

In regard to the research theories, an involvement of Social Cognitive Theory can be adopted and adapted to the Sustainable Household IoT E-waste Management Model to further understand, predict, and changing of human behavior, specifically the consumers within the Household IoT E-waste Management System. Apart from that, the guideline developed could also be extended into developing a monitoring system for Household IoT E-waste or Household E-waste as a whole. A Stakeholder Theory can be adapted into the study to investigate the links between the system performance and the practice of stakeholder management.

The guideline developments are limited to the IoT e-waste management for households in Malaysia. Hence, the adoption and adaptation of our guidelines for other countries will have to be aligned with their policy and regulations on e-waste management. This will not only contribute to a more effective and efficient household E-waste monitoring but also may as well reduce the number of E-waste being discarded in landfills which will eventually ensure a sustainable environment in the future.

8. Conclusion

The study explores household E-waste in Malaysia, where an increase in number is expected in the near future. While Malaysia is still lacking in the regulation of household E-waste as a general, the production of E-waste is expected to increase significantly, concurrent with the movement of the Industrial Revolution, which highly adopts emerging technologies, including IoT devices. Thus, developing the guideline of Sustainable IoT E-waste Management for Household is part of the strategy to fight the rapid increase of E-waste dumped in landfills, especially from IoT devices, which might also introduce the new phenomenon called "IoT E-waste". The study adopts case study method in which three cases of participants that represent the user of IoT devices in a household are interviewed to get a thorough experience and idea on the way participants managed their E-waste, issues and challenges and how could the management be improved to contribute towards the development of the guideline.

The participants represent the users of different backgrounds and experiences, such as those experienced in E-waste collection, IoT technology development, and IT consultants. Thus, three cases were studied based on their background and experiences to collect the necessary data to develop the guideline. An Integrated Sustainable Waste Management Model (ISWM) is adapted to form a new model, which is then used to guide the research study as well as the structure of guideline development. Apart from that, a report on the Collection, Storage, Handling and Transportation of Household E-waste in Malaysia suggested by JICA

Expert Team from the Department of Environment (DoE) is referred for guideline key contents.

To ensure the quality and effectiveness of guideline deliverance, three experts are chosen to review the document while the experts' suggestions are applied to amend where necessary. The experts are selected based on their qualifications, credibility and experience related to the research topic. Furthermore, the guideline itself focuses on several actions to be taken by stakeholders, including the government, generators, consumers of IoT, Collectors or NGOs, formal recycling facilities, and producers or manufacturers of IT products. Hence, the guideline itself is aimed to be used by policymakers in Malaysia to assist them in the regulation development for future household E-waste management.

Credit author statement

Marym Mohamad Razip: Conceptualization, Methodology, Software, Writing – original draft preparation. and **K.S.Savita**: Conceptualization, Methodology, Software, Writing – original draft preparation. Supervision and Validation of Data- Reviewing Writing – original draft, **Khairul Shafee Kalid**: Validation of Data, Reviewing and Editing ., **MN Ahmad**: Validation of Data, Reviewing and Editing .and **Maryam Zaffar**: Validation of Data, Reviewing and Editing .**Eidia Erriany Abdul Rahim**: Supervision and Validation of Data- Reviewing Writing – original draft., **Ali Ahmadian**: Supervision and Validation of Data- Reviewing Writing – original draft. and **Dumitru Baleanu**: Supervision and Validation of Data- Reviewing Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are grateful to the university administrations for their support, as well as funding under Universiti Teknologi PETRONAS (UTP) National Collaborative Research Fund (No:015MD0-098).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chemosphere.2022.134767.

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