UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A SUSTAINABLE HEALTHCARE WASTE MANAGEMENT MODEL USING HYBRID MULTIPLE DECISION MAKING MODEL

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By

MARYAM KHADEM GHASEMI

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

May 2018

Specially dedicated to:

My beloved husband Ali

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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May 2018

Chairman: Professor Rosnah bt. Mohd. Yusuff, PhD
Faculty: Engineering

Healthcare waste treatment (HCWT) has become one of the most significant concerns in the world, especially in developing countries. Between 10–25% of healthcare waste is regarded as infectious and hazardous that may pose the health hazard to staffs and patients as well as environmental pollutions. Therefore, safe and reliable methods for handling healthcare waste are essential. Inadequate and inappropriate management of healthcare waste may have serious public health consequences and a significant impact on the environment. Since in Malaysia the quantity of clinical waste disposed at incinerators in 2013 increase by 17.5% as compared to 2009, the selection of appropriate healthcare waste treatment and disposal technologies for the safe and secure management of healthcare waste (HCW) is significantly important to avoid human health and environmental issues.

Thus, this dissertation aims at developing a multi-criteria decision-making (MCDM) model for healthcare waste treatment and selection in healthcare industries as well as providing a list of applicable criteria and sub-criteria for effectiveness alternative healthcare waste treatment. This study proposed a model to facilitate the decision-making process and help managers of healthcare centres in decision-making. There are four technologies of healthcare waste treatment such as incineration, autoclaving, microwaving, landfilling, and plasma pyrolysis technologies. For selecting treatment technologies for HCWs, decision-makers have to take into account various important criteria simultaneously for successful outcomes and optimal decisions. The sustainability is a natural subject of MCDM includes four subsets of criteria: economics, environmental, technical and social aspects. Therefore, the evaluation of HCW treatment technologies, as a complex MCDM problem, needs to trade-off multiple conflicting criteria with the involvement of a group of healthcare waste management experts.

A set consisting of 4 main criteria and 17 sub-criteria were identified as sub-criteria that affect in selecting the effective healthcare waste treatment method. When a decision is made, there is a need to look at all of the potential relationships/dependencies among the criteria. Also, the correlation between the aspiration-level factors and the alternatives of a system are necessary to be shown that are closest to the ideals solution based on the weights of each factor. To respect to these issues, a hybrid MCDM model combining DEMATEL, ANP, VIKOR and GRA methods applied. At first, a model of a set consisting of main criteria was developed, using experts' opinions. Then DEMATEL analysis carried out to develop a cause and effect model and identify those that need to be improved first. Based on the result, the economic criterion has the highest effect, followed by technical and social and environmental criteria have the lowest effect.

The DANP used to identify important criteria for selection of sustainable healthcare waste (SHCW) technology in Malaysia based on the interrelationships that release with health effects, community and staff acceptance and land requirement identified as three top most important criteria. After that, VIKOR with influential weights (DANP) applied to rank and develop a sustainable healthcare waste treatment (SHCWT) model. The ranking order of the alternative treatments were non-incineration respectively steam sterilization, plasma pyrolysis and microwave on the basis of the technical, economic, social and environmental aspects and their related criteria. Hence it arrives at a decision for the final technology selection based on the principles of sustainability. For verifying this method, the ranking result compared with another MCDM method involving GRA. It observed that the top-ranked alternatives match those derived by both of them as well as previous studies.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL PENGURUSAN SISA PENJAGAAN KESIHATAN LESTARI MENGGUNAKAN MODEL HYBRID MEMBUAT KEPUTUSAN PELBAGAI

Oleh

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Rawatan sisa penjagaan kesihatan (HCWT) telah menjadi salah satu perhatian utama di dunia, terutamanya di negara-negara membangun. Antara 10-25% sisa penjagaan kesihatan dianggap sebagai berjangkit dan berbahaya yang boleh memberikan ancaman kesihatan kepada kakitangan dan pesakit serta menyebabkan pencemaran alam sekitar. Oleh itu, kaedah yang selamat dan boleh dipercayai untuk pengendalian sisa penjagaan kesihatan adalah penting. Pengurusan sisa penjagaan kesihatan yang kurang mencukupi dan tidak sesuai mungkin boleh mengakibatkan masalah kesihatan awam dan kesan yang ketara terhadap alam sekitar. Oleh kerana di Malaysia kuantiti pelupusan sisa penjagaan kesihatan telah meningkat kepada 17.5% pada tahun 2013 berbanding 2009, pemilihan rawatan sisa penjagaan kesihatan yang sesuai dan teknologi pelupusan yang selamat sangat penting untuk mengelakkan isu-isu alam sekitar dan kesihatan manusia.

Oleh itu, disertasi ini adalah bertujuan untuk membangunkan model (MCDM) membuat keputusan pelbagai kriteria untuk rawatan sisa penjagaan kesihatan dan pemilihan industri penjagaan kesihatan serta menyediakan senarai kriteria dan sub kriteria yang boleh diguna pakai untuk keberkesanan alternatif kepada rawatan sisa penjagaan kesihatan. Kajian ini mencadangkan model untuk memudahkan proses membuat keputusan dan membantu pengurus pusat kesihatan dalam membuat keputusan. Terdapat empat teknologi rawatan sisa penjagaan kesihatan seperti pembakaran, autoklaf, microwave, tapak pelupusan dan teknologi pirolisis plasma. Bagi memilih teknologi rawatan untuk HCWs, pembuat keputusan perlu mengambil kira pelbagai kriteria penting secara serentak bagi mendapat keputusan yang betul dan optimum. Kelestarian merupakan subjek asas MCDM yang meliputi empat kriteria sub set iaitu: ekonomi, alam sekitar, teknikal dan sosial. Oleh itu, penilaian teknologi rawatan HCW sebagai masalah kompleks MCDM perlu mengambil kira pelbagai kriteria yang bercanggah dan memerlukan penglibatan sekumpulan pakar-pakar dalam rawatan sisa penjagaan kesihatan.

Satu set yang terdiri daripada 4 kriteria utama dan 17 sub kriteria telah dikenalpasti sebagai sub kriteria yang mempengaruhi dalam memilih kaedah rawatan sisa penjagaan kesihatan yang berkesan. Apabila keputusan dibuat, terdapat keperluan untuk melihat semua hubungan/kebergantungan potensi kriteria. Selain itu, hubung kait antara faktor-faktor tahap aspirasi dan alternatif sistem adalah perlu untuk ditunjukkan sebagai penyelesaian ideal berdasarkan kewajaran bagi setiap faktor. Mengambil kira kepada isu-isu ini, model MCDM hibrid yang menggabungkan kaedah-kaedah DEMATEL, ANP, VIKOR dan GRA telah diguna pakai. Pada mulanya, model satu set yang terdiri daripada kriteria utama dibangunkan, menggunakan pendapat pakar. Kemudian analisis DEMATEL dijalankan bagi mengenal pasti sebab dan akibat serta apa yang perlu diperbaiki terlebih dahulu. Berdasarkan keputusan ini, kriteria ekonomi didapati mempunyai kesan tertinggi, diikuti kriteria teknikal dan sosial manakala kriteria alam sekitar didapati mempunyai kesan yang paling rendah.

DANP telah digunakan untuk mengenal pasti kriteria penting untuk pemilihan teknologi rawatan sisa penjagaan kesihatan lestari (SHCW) di Malaysia berdasarkan hubungan sesama yang bersangkut dengan kesan kepada kesihatan, penerimaan masyarakat dan kakitangan dan keperluan tanah yang dikenalpasti antara tiga kriteria paling penting. Selepas itu VIKOR dengan berat berpengaruh (DANP) digunakan untuk menentukan model rawatan sisa buangan kesihatan lestari (SHCWT). Susunan kedudukan rawatan alternatif termasuklah ketidak-insinerator, wap sterilisasi, pirolisis plasma dan ketuhar gelombang mikro yang berdasarkan aspek-aspek teknikal, ekonomi, sosial dan alam sekitar dan kriteria berkaitan mereka. Justeru aspek ini digunakan untuk membuat keputusan untuk pemilihan akhir teknologi berasaskan prinsip-prinsip kelestarian. Bagi mengesahkan kaedah ini, keputusan kedudukan telah dibandingkan dengan satu lagi kaedah MCDM yang melibatkan GRA. Keputusan ini mendapati bahawa alternatif paling tinggi adalah sepadan dengan apa yang diperoleh oleh kedua- dua kaedah dan sepadan juga dengan kajian sebelumnya.

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Last but not least, thanks to my beloved husband Ali. I owe you everything.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

MSW	Municipal solid waste
GSW	General solid waste
HCW	Healthcare waste
RMW	Regulated medical waste
HCWM	Healthcare waste management
MCDM	Multi-criteria decision making
DOE	Department of environment
MOH	Ministry of health
AHP	Analytic network process
VIKOR	VIsekriterijumska optimizacija I KOmpromisno Resenje
ELECTER	ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing the REality),
ANP	Analytic network process
ITL-MULTIMOORA	Interval 2-tuple linguistic - multi-objective by ratio analysis
DEMATEL	Decision-making trial and evaluation laboratory
TOPSIS	Technique for order preference by similarity to ideal solution
WHO	World health organization
GHG	Greenhouse gas
MWI	Medical waste incinerators
BAT	Best available techniques
BEP	Best environmental practices
EPA	Environmental Protection Agency
POTW	Publicly owned treatment works
NPDES	National pollutant discharge elimination system
OAC	Ohio administrative code
EMS	Environmental management system
CBA	Cost-benefit analysis
LCA	Life cycle analysis
NRM	Network relations map
KM	Knowledge management
FAHP	Fuzzy analytic hierarchy process
HCWT	Healthcare waste treatment
GRA	Grey relation analysis
SHCWT	Sustainable healthcare waste treatment

CHAPTER 1

INTRODUCTION

1.1 Introduction

This part includes the background of the issues that are relevant to the topic of research. Healthcare waste treatment (HCWT) evaluation and selection is a very critical issue in the success of healthcare waste management (HCWM) of organizations. This thesis proposes a sustainable decision-making model for evaluating and selecting the most suitable healthcare waste treatment and provides a list of sustainable criteria and their corresponding sub-criteria as well as measure their relationship and importance. In the following, the sub-sections related to the background of the study, problem statement, research aims and objectives, scope of the research, contribution of the research and organization of the research are presented.

1.2 Background of the study

Currently, HCWT has become one of the most significant concerns in the world especially in developing countries in terms of obtaining successful outcomes (Eleyan et al., 2013; Thakur and Ramesh, 2015). Since healthcare centres and hospitals are institutions providing various healthcare services to the community and are places for treating patients, they can also be places to spread disease (Borg, 2007). Between 75% and 90% of hospital, waste is non-risk or "general" healthcare waste, comparable to municipal solid waste (MSW). The remaining 10–25% of hospital waste is regarded as infectious and hazardous, and may pose a variety of health risks (Chaerul et al., 2008a; Pandey et al., 2016).

The waste produced in healthcare can be divided into four main classes: (1) hazardous and infectious waste that might contain pathogens (2) hazardous waste that can cause injury without infection (3) non-hazardous waste and (4) general solid waste comparable to domestic waste (Giacchetta and Marchetti, 2013). Therefore, safe and reliable methods for handling healthcare waste are essential. Inadequate and inappropriate management of healthcare waste may have serious public health consequences and a significant impact on the environment (Prüss et al., 2013; Xiao, 2018). The inappropriate management of healthcare waste practice can, directly and indirectly, pose health hazards to staffs and patients to many diseases like cholera, HIV, dysentery, skin infection, infectious hepatitis, as well as environmental pollutions (Coker et al., 2009; Sawalem et al., 2009; Patwary et al., 2009; Hossain et al., 2011). In this respect, for safe and secure management of healthcare waste, the waste management plans should be developed to minimize the risks and overall management cost (Graikos et al., 2010).

Four major recommended categories of HCW for organizing segregation and separate storage, collection and treatment are sharps, whether infectious or not; non-sharps infectious waste; general waste; and hazardous waste (Xie and Zhu, 2013). Incineration, disinfection, sterilization, plasma, and land filling have been adopted for the treatment of HCW in different parts of the world (Asante et al., 2013). HCW treatment technologies are often classified into the burn and non-burn technologies and have their inherent qualities, demerits and application criteria (Prem et al., 2010). Incineration methods are the most used technique for healthcare waste treatment. In any case, the main purpose of the treatment technology is to clean up waste by destroying pathogens (Lee et al., 2004; Katoch and Kumar, 2008; Xiao, 2018).

In Malaysia, the number of healthcare institutions is changing at a rapid rate as hospitals add new services and change procedures on an annual basis as they refocus and upgrade operating activities. The quantity of clinical waste disposed at incinerators in 2013 increase by 17.5% as compared to 2009 (Pariatamby, 2017). In Malaysia a set of regulations, dealing with hazardous waste management which regulates the storage, transport, treatment and disposal of hazardous wastes was enforced since May 1989:

- Environmental Quality (Scheduled Wastes) Regulations, 2005 (to replace the Environmental Quality (Scheduled Wastes) Regulations 1989);
- Environmental Quality (Prescribed Premises) (Scheduled Wastes Treatment and Disposal Facilities) Regulations, 1989; and
- Environmental Quality (Prescribed Premises) (Scheduled Wastes Treatment and Disposal Facilities) Order, 1989.

It is a fact that incineration is the main disposal method of medical waste in Malaysia. In recent years in this country, the quantity of medical waste generation and the public concerns about the inappropriate treatment and disposal of medical waste has been increased. By the year 2020, biomedical waste from Malaysian hospitals is estimated to hit 33 000 tones yearly. Currently, the capacity of incineration in this country is limited to processing 18 000 tonnes of wastes per year (Frost and Sullivan, 2010; Ambali et al., 2013). The Malaysian government must consider the healthcare waste strategies more systematically and stringently, to control cost and manage healthcare waste appropriately, as it can reduce the hazards and risks to the community and the ecosystem. So, other potential treatment technologies must be examined as alternatives to incineration in order to better manage medical waste in Malaysia.

In the past decade, environmental and social concerns have attracted significant attention in the name of sustainable development. Due to the increasing awareness of environmental protection, increasing attention in sustainable management and the development of theory to support sustainable managerial decision-making, sustainability has become very important to organizations (Govindan et al., 2013). Waste management systems should incorporate suitable environmental and social indicators, which can be potentially used in multi-criteria analyses. For a waste management strategy to be effective, successful and sustainable, it must consider environmental, social and economic aspects (Antonopoulos et al., 2014). Moreover, Waste management is affected by technical, environmental, financial and social as the factors that evaluate the performance of the system (Govindan et al., 2013). As far as standards for operating HCW treatment facilities are concerned, every country uses

different criteria to establish its waste treatment technology according to the experience of the experts and decision-makers. So, the final selection of the best treatment system should be made carefully, on the foundation of different factors, many of which rely on local conditions (Yang et al., 2009; Achillas et al., 2013). Selected criteria must cover main dimensions of sustainable development, such as environmental, social, technical and economic aspects (Ibáñez et al., 2014).

Up to now, a variety of mathematical techniques and methods have been developed and conducted in various contexts to solve HCW treatment selection problems (Dursun et al., 2011b; Sun et al., 2012; Shi et al., 2017). On the other hand, the selection of the best treatment technology for HCW management can be regarded as a complex multi-criteria decision-making (MCDM) problem (Iglesias et al., 2008; Zavadskas et al., 2016). Decision makers often assess the ratings of alternatives against multiple and hierarchical evaluation criteria (Lee et al., 2004; Diaz et al., 2005; Rogers and Brent, 2006; Dursun et al., 2011a; Liu et al., 2014).

Due to the complicated relationships among the multiple and hierarchical evaluation criteria, efficient decision models are required to select the most appropriate HCW treatment technology. Hence, many approaches were presented and incorporated to trade-off multiple conflicting criteria with the involvement of a group of decision makers, such as, the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Liu et al., 2013), the analytic network process and elimination and choice expressing the reality (ANP and ELECTRE) (Özkan, 2013), the analytic hierarchy process (AHP) (Karagiannidis et al., 2010; Milutinović et al., 2014), Multi-Objective Optimization by Ratio analysis plus Full Multiplicative Form (MULTIMOORA) (Liu et al., 2014), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) (Lu et al., 2016).

The main problem associated with the existing decision analysis methods is that most of them cannot handle the analysis of complicated and bidirectional relationships among various hierarchical levels of criteria. However, the decision to determine the most suitable HCW treatment technology requires a decision model that performs just that analysis in Malaysia. Therefore, the issue of the previous MCDM approaches in HCWT selection is the HCW decision makers are unable to analyse HCWT methods when they do not know the relationship between the determined criteria.

This research study focuses on the development of decision-making model using a hybrid MCDM application for alternative treatment optimal technologies of healthcare waste. Asa well as provides a list of the most important and applicable criteria and sub-criteria for HCWT evaluation in Malaysia.

1.3 Statement of problem

The generation of healthcare waste in the world has increased significantly over the last few decades. The appropriate handling and disposal of healthcare wastes generated from hospitals and other health care institutions and facilities is essential in order to

relieve against adverse health and environmental consequences (DOE, 2009). The Ministry of Natural Resources and the Environment has Environmental Quality Act 1974 (Act 127). The act's scopes are to prevent, reduce, and control pollution and to enhance the environment (Yusof et al., 2016). On the other hand, the Malaysian Government through the Department of Environment has formulated its vision, that is, to contribute towards nation building in attaining a better level of health, safety and quality of life through control of pollution towards sustainable development (Behzad et al., 2011). Therefore, the selection of appropriate healthcare waste treatment and disposal technologies for the safe and secure management of HCW is significantly important to avoid human health and environmental issues. When selecting treatment technologies for HCWs, decision-makers have to take into account various important criteria or factors simultaneously for successful outcomes and optimal decisions. Each treatment technology has different performance for each evaluation attribute.

On the other hand, sustainability is a natural subject of MCDM, because, by itself, it includes three subsets of criteria: economics, environmental, and social aspects (Antucheviciene et al., 2015). When analysing sustainable industries, the fourth subset of criteria involving engineering and technological dimensions is also important. Therefore, the evaluation of HCW treatment technologies, as a complex multi-criteria decision making (MCDM) problem, needs to trade-off multiple conflicting criteria with the involvement of a group of experts. When a decision is made, there is a need to look at all of the potential relationships/dependencies among the criteria, since the assumption of independence, is not consistent with conditions in the real world (Saaty, 1996).

Many mathematical techniques and traditional multiple criteria decision-making (MCDM) methods such as ANP with the independence assumption of individual criterion applied to solve the problems of the HCW management from numerous countries and them cannot handle the analysis of complicated and interrelated relationships among different hierarchical levels of criteria. Each individual criterion could not be always completely independent. In addition, there are different degrees of influence among the criteria in the real world. However, the correlation between the aspiration-level (desired) factors and the alternatives of a system are necessary to be shown as well as the distinction between the negative and the positive criteria that are closest to the ideals solution based on the weights of each factor. To respect to these issues, a novel hybrid MCDM model has to develop to overcome the limitations of decision models, which can be used to help engineering designers analyse the interrelations between criteria and the achieving the aspired levels in selecting of HCW treatment technologies. On the other hand, only a limited number of studies have appeared in the literature, which was directly or indirectly related to select the effective healthcare waste treatment (mentioned in background of the study) and a thorough survey of the literature has revealed that no work in the Malaysian context to determine the suitable treatment technology (Zainu et al., 2015).

1.4 Research objectives

This research aims to develop a multi-criteria decision-making model for healthcare waste treatment and selection in healthcare industries as well as providing a list of

applicable criteria and sub-criteria for effectiveness alternative healthcare waste treatment. This study proposed a model to facilitate the decision-making process and help managers of healthcare centres in decision-making.
This study was conducted with the following research objectives (RO) and research questions (RQ):

RO_1: To develop a framework of the applicable criteria and available alternatives for the evaluation of the effective HCW treatment.

RQ_1: Which list of criteria is suitable to evaluate the effective healthcare waste treatment?

RQ_2: What are the available treatment alternatives for healthcare waste in Malaysia?

RO_2: To develop a cause and effect model to find influential interrelationship among main criteria and sub-criteria.

RQ_1: How to assess the interrelationship among criteria and sub-criteria?

RO_3: To develop the influential weights of criteria that influence the selection of sustainable healthcare waste treatment (SHCWT) alternatives.

RQ_1: What are the most important criteria/factors that influence the selection of SHCWT alternatives?

RO_4: To develop a sustainable treatment of healthcare waste to achieve the ideal solution or aspiration level.

RQ_1: How to assess the sustainability of HCWT.

RO_5: To investigate the performance of the proposed model using the different methods.

RQ_1: How to evaluate the accuracy of the developed model?

1.5 Significance and contribution of the study

The goal of most cases of waste management is to create a balance between cost of service, environmental impact, demands for service and societal needs. World Health Center (WHO) has published the principles describing the safe and sustainable management of healthcare wastes, as a necessity in public health issues, and also the procedure to achieve all the related measures to supply the needed financial resources (WHO, 2008). Different technologies (incineration and non-incineration) for healthcare waste treatment are available. Therefore, healthcare decision makers must select cost-effective and effective treatment for their healthcare wastes to decrease volume and reduce cost as well as prevent environmental hazards and protect occupational safety. Therefore, the current study proposed a decision-making model for HCWT evaluation and selection with respect to sustainability for decision makers in healthcare industries. One of the contributions of this study was to develop an effective list of criteria and their relative sub-criteria for using a semi-structured interview for the assessment of healthcare waste treatment in healthcare industries.

This study also contributes to the use of MCDM methods in the area of treatment selection of HCW. As stated before, the existing MCDM models in the area of in healthcare waste treatment cannot generate an interrelationship between criteria and develop a cause and effect model (mentioned in chapter 2). In this research, the decision-making model is developed using MCDM method that can be used to help

engineering designers and decision makers analyze the interrelationships in the selection of HCW treatment technologies as well as derive the solution with the highest relevancy to overcoming the gap between the current state and the aspired level of HCWT.

1.6 Scope of research study

The scope of this study was to analyze the alternative treatment of healthcare waste in hospital industries in Malaysia. Other areas of focus included five alternative healthcare waste technologies and a finite set of decision criteria in terms of sustainable development. These sustainability issues and treatment of healthcare waste with consideration of sustainability have received much attention in recent decades. Therefore, it is competent to conduct a research in sustainability scope. Healthcare industries are where that strongly need to focus on sustainable healthcare waste treatment alternatives selection.

However many studies have been done in this area, but it is seen that there is a need to determine a comprehensive a list of criteria and their corresponding sub-criteria and measure their importance and applicability. In addition, it can be seen that in the recent decade among the existing models, the decision-making models have been progressively used for solving the problem of HCW treatment evaluation and selection. However, these models are very valid, but the existing models cannot provide the decision makers with an explicit mathematical model for healthcare waste management based on the criteria. So, there is a need to introduce a new decision-making model for solving the HCW problem in the field of sustainable HCWT selection.

The scope of this study is to develop a decision-making model for HCWT selection based on the importance and interrelationship sustainability criteria for the healthcare industry. In fact, by developing the list of the criteria and sub-criteria, the managers of the healthcare industries can understand how to evaluate the sustainability of HCW treatment. In addition, by measuring their interrelationship and importance, the decision makers can understand which criteria are the most effective confidants on the sustainability HCW treatment. Furthermore, by implementing the decision-making model the decision makers can analyze the functioning of the waste treatment device and achieve the best treating process.

1.7 Structure of thesis

The material in this research was organized into five chapters. Chapter 1 provided a general overview of the thesis. A review of the relevant literature on HCW management practices is given in chapter 2. In chapter three, the methodology of research, a hybrid MCDM model combining ANP, DEMATEL and VIKOR-GRA for assessment of HCW treatment technologies, evaluation methods for verifying the model is developed. In chapter 4, an empirical case conducted in Malaysia is presented to demonstrate the new decision framework. Moreover, five objectives are achieved in this chapter. Finally, summarizes the research, conclusions, future research and limitation are provided in chapter 5.

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