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REVIEW

A Review of Solid Waste Management using System Dynamics Modeling

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Abstract

Solid waste management is currently a topic of concern, particularly in the protection of humans and the environment from toxic pollutants and hazardous materials. The importance of solid waste management is recognized at international, national, and community levels. Different agendas have been prioritized and assigned to improve quality of life, productivity, and health, and reduce the burden of pollution. Suitable management of solid waste requires appropriate technology that is affordable, socially accepted, and environmentally friendly. The use of a smart management system involving system dynamics can save energy, money, and labor. System dynamics is a computer-based approach that aids in predicting the behavioral patterns of variables, and correlating dependent and independent variables. The inclusion of system dynamics-based models in solid waste management has recently become more common. In this review, we used system dynamics to determine methods to disentangle solid waste management systems and analyzed different studies on solid waste management using system dynamics in different countries in detail. We also discussed the various software packages that are available for system dynamics and their usefulness for waste management. This review may help in understanding current solid waste management practices using system dynamics.

Key words : Solid waste, Solid waste management, System dynamics, Software

1. Introduction

In this century, generation of Solid Waste (SW) is the global concern that mostly impacted by rapid urbanization, industrialization (Fang et al., 2017; Wang et al., 2017) and population growth (Du et al., 2017; Islam, 2017). Therefore, the sustainable management of SW will be necessary at all phase to plan a design for operation. The necessity of an orderly evolution will allow the waste management industries and different government agencies to meet unified goals of Solid Waste Management (SWM) with a greater potential. Recycling of materials out from the waste streams, enlargement of the renewable energy management and importantly- a socially acceptable non-technical aspects of a SWM system should be analyzed as a whole, since all of them are correlated with one another and also developments in one area often upset the activities in another area. The population has been defined as the most important factor which can affect the other variables, when defined in any system (Dodds et al., 2012). Moreover

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to achieve an improved quality of life, increase productivity, improved health and reduce the burden of pollutions: United Nations has declared different agendas. They are minimizing wastes, particularly waste destined for final disposal; maximizing the reuse and recycling waste environmentally; promoting disposal and treatment waste environmentally; extending solid waste service coverage to all urban and rural areas (Sitarz, 1993; Kassim, 2012).

These goals with the different priorities can be achieved through a range of integrative methodologies named as System Analysis Techniques (SAT) which are being used by every community to manage various components of the waste streams in a flexible manner. Among all SAT, recently the use of System Dynamics Modeling (SDM) approach was most often seen with a focus on management of SW (Pai et al., 2014; Bufoni, 2017; Giannis et al., 2017; R. Zhao et al., 2017). Therefore while managing SW, sectors like environment, recycling, business, ecology, socio -economic systems, population, Gross Domestic Product (GDP), regulation (legal), generation rate, and sorted waste considered (Karavezyris et al., 2002; Dyson and Chang, 2005; Kollikkathara et al., 2010; Zhao et al., 2011; Dace et al., 2014; Yuan and Wang, 2014; Sukholthaman and Sharp, 2016). Moreover, European countries like Germany, Latvia etc. and Asian countries like China, Thailand, India and United States of America have been working with SDM approaches.

With system dynamics approaches every community can manipulate their own system to manage various compartments of SW systems in an appropriate way and may connect the real world and the modeling world as shown in Fig. 1. Yet, the usefulness of this novel approach to remove the barriers from different areas of study is limited in knowledge to people. Therefore, this review is for gaining awareness among the readers by pointing out different scenarios and the involvement of SDM to solve the issues of solid waste. Moreover, an effort was put to answer the following key queries: (1) the gaps in existing knowledge of SWM which are needed to achieve in the context of sustainable development in the long run (2) a discussion about various software are available for system dynamics with their limitations and their updated options with powerful features and flexibility, (3) the achievements with SDM that have been reached to solve different critical problems in different countries, and (4) the research essentials and future directions in SDM for SWM.

2. Current solid waste management principles and its requirements for SDM:

To understand the proper scenario and solving -potentials of different critical problems of solid waste with SDM, primarily awareness for SWM principles are necessary. The large amount of money, manpower and proper technical knowledge is involved for the management of solid waste. To address this, solid waste management includes

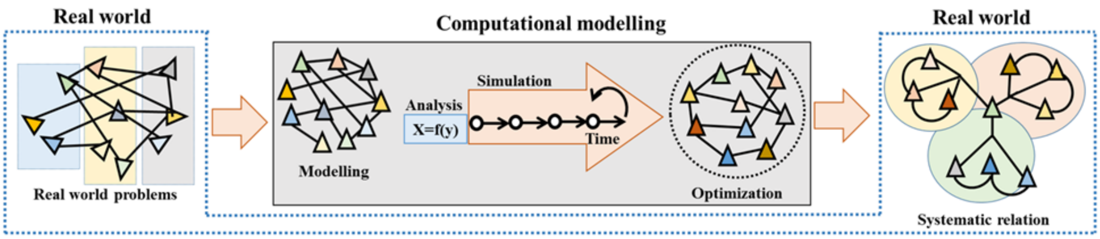

Fig. 1. Diagram to show the relation of system dynamics modeling to the real world.

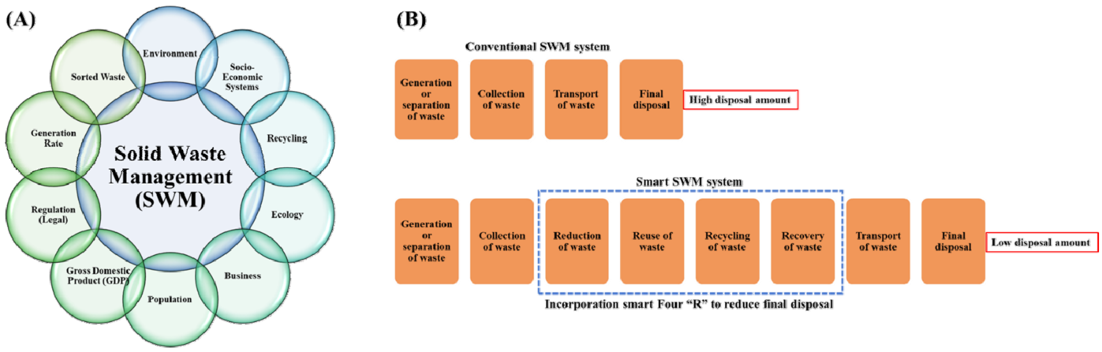

Fig. 2. (A) This diagram explains the different outputs of solid waste management and their connections with different aspects. (B) The diagram represents an example of conventional waste management system and the involvement of "Four R" that helps in decreasing the amount of final disposal than the conventional process.

following terms in sequence such as generation, collection, separation or sorting, transportation and treatment of the collected waste (Mcallister, 2015). The poor solid waste management may cause plenty of serious health and environmental problems. The piles of uncollected and untreated waste get accumulate in different urban and rural areas, causing health problems and environmental degradation. But the adaptation of any of the four R's (i.e. Recycle, Reuse, Recovery and Reduction) of solid waste management could be used to minimize the risk of the environment and human health (Limbu, 2014) as shown in Fig. 2. In this current era for the growing concern that has an impact on the environment; the society demands the waste management to be sustainable and thus involves the recycling of waste (Kassim, 2012; Schiopu and Ghinea, 2013; Bello and Haruna, 2015; Nassar, 2017). Therefore, the proper management of solid waste needs appropriate technology, which is economically affordable, socially accepted and environmentally friendly (Kassim, 2012; Bello and Haruna, 2015). The need of proper waste management is necessary for the following reasons: to control different types of pollution (e.g. air, soil, water etc.) (Parate and Shinde, 2016) to stop spreading infectious diseases (Dege, 2011) to conserve environmental resources from the contamination; and, to recycle of hazardous waste from further contamination (Wahid, 2012; Wahid and Governorate, 2013; Mombelli et al., 2015)

The overall aim of SWM is to achieve the improved quality of life. This could be accomplished by creating supportable communities capable of managing available resources efficiently with an innovating potential of the economy to ensure prosperity and by protecting environment. These changes will bring about a sense of urgency in SWM. While short-term action is required for tackling operational issues in SWM, maintaining a long-term perspective of SWM also needs to be set out (Pires et al., 2011). In addition, key challenges in relation with long-term waste management can influence climate change and energy use, linking SWM systems with the reduction of Greenhouse Gas (GHG) emissions and the enhancement of energy recovery; a requirement of smart waste management is necessary. Smart waste management has two functions, such as operational efficiency and waste reduction (Shukla, 2016), and it can reclaim areas overrun by trash and mitigate the dependence on urban landfills (Lawrence and Woods, 2014). It has a special need in this current world to maintain and protect the ecology and to prevent pollution from different hazardous materials (Marshall and Farahbakhsh, 2013).

2.1. Basic introduction to SDM and its software with their pros and cons:

SD is a methodology for analyzing complex systems and problems over times with the aid of computer simulation software (Sterman, 2001). It follows few steps, including making a loop diagram, connecting the variables, and chalk out the relation among them (direct or inverse) (Forrester, 1994). SDM can help in building the communication and to identify the feedbacks among different related components in a system that enhance the decision making policies in different scenarios (Homer and Hirsch, 2006; Vinkenburg, 2017). For example, the policy of taxing on packaging material (e.g. plastic cover, paper box, etc.) can help to reduce the solid waste generation (Dace et al., 2014). Moreover, solid waste is used as fuel to generate the electricity through biomass gasification gases (Asadullah, 2014). Before going in detail of the use of SDM in SWM system, in this section the brief knowledge of different software has been detailed with the pros and cons. The mostly used software tools includes Ventana Simulation (Vensim, 2013), System Thinking for Education and Research (STELLA) (Chalupsky et al., 2006) and Powersim Studio 8 (Dace et al., 2014). The software tools of system dynamics are divided into various categories (Sumari and Ibrahim, 2013) on the basis on their area of use, as describe below:

2.1.1. Core software

Core itself means the essential or important; hence, core software may define as the software, which are important and use in majority of the works. They use for making and simulating the system dynamics models. The core software tools are STELLA (Chalupsky et al., 2006), Vensim (Vensim, 2013) and Powersim Studio (Dace et al., 2014).

2.1.2. Extensive software

Extensive software covers a large area of works, as they are essential for the building and simulation purpose of SDM; moreover, they can support the other forms of modeling and the diagrammatic representations and for the model that uses differential forms of equations. For example, some of them are known as, Dynaplan, Berkeley Madonna, Goldsim, Simile (from Simulistics), and Simgua, described in Table 1.

2.1.3. Other software

The other software fall under the category of Web based tools, tools for documentation; Model coordinating tools/Model analysis tools; as they are web based modelling, model development or model execution. The extensive software are important for document related work and essential to understand any model structure and its relationship behavior, respectively. For example, such software tools are Insight Maker (Fortmann-Roe, 2014), BROADVIEW (Tackett et al., 2013), iMODELLER (Long, 2004), NetLogo (Tisue and Wilensky, 2004).

2.2. The importance of system dynamics in solid waste management

The system dynamics is a high-level graphical simulation program, which involves the mathematical mapping of system with stock and flow diagrams. The simulation involves various steps: (1) identification of the problem; (2) identification of the most important stocks and flows that change these stock levels; (3) identification of the sources of information that impact the flows; (4) identification of main feedback loop; (5) drawing of a casual loop diagram that links the stocks, flows and sources of information; (6) writing of the equations that determine the flows; (7) estimation of the parameters and conditions by statistical methods, by market research data, by relevant sources of information; (8) simulation of the model and analysis of the results (Martinez-Moyano and Richardson, 2013) as described in Fig. 3. At

Table 1. Detail information of different SDM software and their utilities

Features	Vensim	STELLA/ ithink	Powersim studio
1. File extension name	.vmf,.mdl	.stm,.stmx,.itm,.itmx	.sip,.sig,.~si,.sir
2. Licensing	proprietary, commercial, Free Personal Learning Edition (PLE) for education and personal use	proprietary, commercial	proprietary, commercial
3. Implementation language	It is a software for system dynamics modeling written in language C	Visual programming language for system dynamics modeling	simulation software written in C++
4. Advantages	(a) Simulation with stock and flow; discrete delay and discrete event functionality (b) It is used for external functions and compiled simulations (c) It supports the time series data import and export with calibration optimization (d) It is used for the Monte Carlo and other sensitivity simulation methods	(a) Model builder is based on intuitive icon based graphical interface (b) Excellent compatibility with all the elements, functions and array structures converted	(a) It is used for sensitivity analysis and optimization (b) It can be used for system dynamics and discrete event modeling
5. Disadvantages	Do not support synthesim and non-simulation features All types of data files cannot be uploaded	Queues, cycle time and ovens functions are not converted	It does not support the time series data import and export calibration optimization
6. Last updated year	2016	2012	2015
7. Discovered year	1990	1985	1994
8. Operating system	Windows and OS X applications, Linux and iOS libraries	Microsoft Windows, OS X	Microsoft Windows
9. Applications	Education, Business-strategy, project management, environment etc.	Academia and commerce ; and education	Education and Business models, Home market business purpose

beginning, the causal loop diagram is important for showing the cause and effect changes between the different variables. For example, the increase of the population and the waste generation per capita can increase the amount of total waste generated and thus it affects the other variables in a SWM model directly or indirectly. The general view of a causal loop diagram has been presented by Fig. 4 to show the direct or indirect connection of one parameter with the other parameter (Chaerul et al., 2008).

Within different methods available to study SWM, the SD has distinctive advantages as it can predict the future trends, study the system characteristics and find the effective ways to solve problems (Dwivedy and Mittal, 2010; Pubule et al., 2015). It also provides the most interfaces for its relatively easy connection with other models. For example, in most of the models population has been described as one of the most important and biggest factor that can affect any variable and waste categorization has been done as general and hazardous (Kollikkathara et al., 2010; Dace et al., 2014). Secondly, the models with similar opinion about the “sorting of waste” (Krook and Eklund, 2010; Pomberger et al., 2017; Robert et al., 2017), also called “source separation” (Zhuang et al., 2008; Han et al., 2016; Chifari et al., 2017; Moh

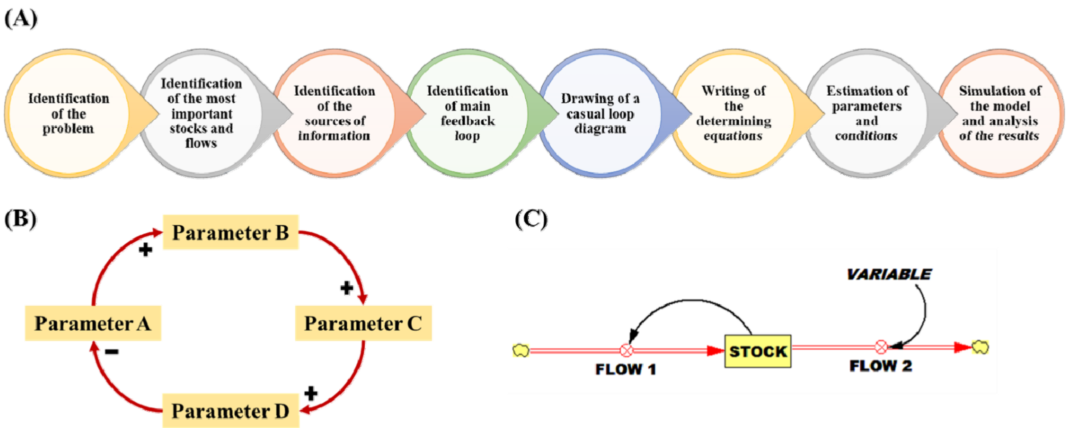

Fig. 3. (A) This is a schematic figure showing the different steps involved in simulation of the system dynamics modeling to analyze the final result. (B) The figure shows the causal loop diagram notation in which the positive sign (+) on the causal link shows the direct relation between the two linked parameters and the negative sign (-) on the causal links shows the indirect relation between the two linked parameters. (C) This diagram is to represent the basic elements of system dynamics in which stock variables (symbolized by rectangles) are the state variables and they represent the major accumulations in the system; whereas the flow variables (symbolized by valves) are the rate of change in stock variables and they represent those activities that fill in or drain the stocks.

and Abd Manaf, 2017; Zhang et al., 2017).

The SDM applied in different studies displays its useful property of making decisions in the future. As example, (1) recycling of SW significantly decreases with the increase of illegal disposal and management (Karavezyris et al., 2002); (2) SW generation increases with the increase of population and income (Dyson and Chang, 2005); (3) the funding policies for waste prevention affect the cost of recycling and landfilling (Kollikkathara et al., 2010); (4) the source separation affects the recyclable and organic waste; waste to landfilling; cost; and collection service efficiency (Sukholthaman and Sharp, 2016); (5) an increased price elasticity of demand for material to help to decrease the materials used per product and the consumption of packaging material (Dace et al., 2014). From the above discussion, SDM is considered as the best option for waste management to go to the further step in any system.

The first documentation of use of system dynamics modeling has been done by Randers and Meadows for solid waste management system in the early 1973. Later, many studies have been performed through worldwide. In this section, some of the important studies have been mentioned which are impactful for the humanity. The discussion about different scenario and the use of SD to solve those problems and the significance of the studies is to help the mankind for betterment has been done.

2.2.1. Recycling would significantly decrease with parallel increase of illegal disposal and management

The issue of recycling the waste is a useful factor, and with the help of SDM, previously, plenty of the disposal problems have been solved. Some breakthrough studies are like, in the Berlin region, at Technical University of Berlin, Germany (Karavezyris et al., 2002) applied system dynamics to solve municipal SW problems; by including the factors like, recycling, environmental behavior, treatment price, collected waste and regulation. With the help of Vensim software, the variables were interconnected. They concluded that recycling would significantly decrease with parallel increase of illegal disposal and management. Further, Giannis et al. (2017) have used the application of SD modeling for studying the different recycling scenarios in Singapore with the use of Vensim software in the year of 2016. They showed that the landfill is not the best option in this small country for the waste disposal. There they focused on recycling of municipal solid waste without hindering the economic growth of the country with using the four sub systems: population, economy, waste recycling and the waste disposal. Madden et al. presented their initial findings from a system dynamics model, developed to assess interventions to improve resource recovery in a multi-stream (municipal, construction and commercial) waste system specific to New South Wales, Australia. The system was characterized by causal feedback processes between waste generation, valorization processes, and waste management policies, making it ideal for study using a system dynamics approach, and offers benefits in terms of greater understanding of the system processes over more typical mechanistic approaches.

2.2.2. Increasing trend in population size and its income parallel increases waste quantity

In the year of 2005, Dyson and Chang took San Antonia, Texas, USA to calculate the generation of municipal solid waste in urban region (Dyson and Chang, 2005). The study was performed under the Department of Environmental Engineering to develop a system dynamics model using Stella software. The model was of five combinations of factors that has influence on the solid waste generation. The variables such as population, household size, household income and waste generation have been connected and compared for getting the results and thus concluded that increasing trend is phenomenal in all the aspects.

2.2.3. Recovery of waste helps in minimizing the cost of landfill

Waste recovery through small scale composting and informal recycling can contribute to waste diversion. This concept has been studied by Kum et al. (2005) for Phnom Penh City, Cambodia by planning of solid waste management with the knowledge of economy and socio-technology was completed with Vensim software. Various factors such as population, labor force, demand for composting etc. were considered. They arrived in a conclusion that the focus was given to composting rather than landfill by municipalities. Waste separation is a key step, which should be done by labor; to give them employment as well as a good life style. With simulation run, it has been found out that waste separation is important variable that can help in decreasing the unit compost production cost. In another study in the year 2016, the urban waste management has been conducted by Marion Micah R. Tinio to feature the economic, environmental and social problems and used the Stella software to connect the important variables such as income, population, marketability of recovered waste for Malolos City, Philippine. The study evaluated the methane emission from organic waste, carbon dioxide emission from paper and plastic waste and concluded how the waste diversion practices could be helpful in saving the volume of generated waste and thus in reducing the emission from solid waste.

2.2.4. Improper landfill can generate different environmental pollutants

Reduction of waste by landfills can emit pollutant like, greenhouse gases. By using system dynamics Talyan et al. (2007) calculated methane emission from the reduction of waste by landfills. There, they recommended treatment methods like Biomethanation, composting and refuse derived fuel for reducing the emission of methane gas. The model thus concluded that using the technologies for different treatment options could reduce the emission of greenhouse gases and thus prevent the environmental pollution. Ojoawo et al. (2012) from the University of Ibadan, Nigeria, conducted one study on the source of environmental hazardous compound leachate from landfill. The model has been developed to study the control over dumpsite leachate production with the help of Stella software. Beside the moisture content in waste which has inverse relation with the production of leachate amount, population also has a direct role in leachate production. The other variables that were included there are precipitation, pan-evaporation, temperature and percent organic content. The model simulation showed that leachate generation could increase with the increase in the income of residents. In 2016, a study of waste management using Delphi method and system dynamics modeling using Stella software was conducted by Hamsah et al. (2016) in Baubau, Indonesia. The model did classify the solid waste management into four aspects, namely, environment, social, economy and technology. This study included the Life cycle analysis and first order decay method as guided by International Panel of Climate Change (IPCC) and Analytical Hierarchy. They put a preference over the composting facilities than any other facility for the treatment of waste. It has also given a quantitative result for the emission of methane. They calculated that combination of five percent recycling, fifteen percent sanitary landfill, thirty-seven percent sanitary landfilling and seven percent composting can reduce the amount of emission of methane from landfill, which can reduce up to forty-two percent emission than current strategies for the year of 2010-2018 in Baubau, Indonesia.

2.2.5. Gross Domestic Product (GDP) of the population is directly related with the pollution

In 2006, a system dynamics modeling was developed by using Stella software for solid waste management in the urban region of Dhaka, Bangladesh (Sufian and Bala, 2007). Here, they proved that money can solve the environmental pollution to a greater extent by reducing the waste to the final disposal and hence increase the quality of environment for people by making a balance between the different variables of waste like waste generation, waste collection, transportation etc. Population, GDP and income per capita have direct relation with the generation of waste. Increasing population can increase the generation of waste thus increase the need for the potential of electricity as well. The relation between the generation and management of waste was well defined in this study with the help of two policies having the different variables. The simulation run of model resulted in the conclusion of increasing the untreated waste with lack of treatment facility can increase the public concern for the waste management over time. In 2012, a system dynamics model of management of solid waste was developed by Ojoawo et al. (2012) by using Vensim software for Western State in Nigeria. He concluded that waste collection is directly proportional to waste generated. Economy of country plays a vital role in handling of the waste. The waste generation could depend on other variables like, urbanization, population growth and life style change of the people.

2.2.6. Environmental policies, planning, implementation and operations directly associated with waste management

In 2007 by doing comparisons with other model Hao et al. (2007) took Hong Kong, China as study area for making a system dynamics model with Stella software for construction and demolition waste management. This model explained about the different stages of waste management. Among them, environmental policies, planning, implementation and operations, checking and corrective actions, measurement review and improvement are most important. Waste has been categorized as material machinery, energy and labor. This model considered total of sixty variables. The drawback of this study was as it lacks in defining a proper and appropriate urban solid management in developing countries. In

2010, Kollikkathara et al. (2010) have developed a system dynamics model to study the economic relation between the generation of waste and the landfill capacity for the urban region of Newark, USA by using Stella software. The model resulted into a conclusion of using funds for the waste prevention measures as it can directly affect the cost of recycling and the cost of landfill. In the coming years recycling will be considered as the best method over landfill for the reduction of waste due to lack of land resources. The amount of waste generation will increase because of growing population and other socio‐economic and demographic factors. This model has solved the problem of waste management but the limitation of this model is only the consideration of the economic variables without considering the other environmental and socio economic variables.

2.2.7. Quality hospital waste management system is significant for an improved health-care system

The study about the hospital waste management by using the Stella software was conducted by Chaerul et al. (2006) in Jakarta, Indonesia in the year 2008. This study has mentioned a new term NIMBY (Not In My BackYard) syndrome that could be minimized by the spread of education and awareness among people. This model is based on the simulation result of different factors such as population, waste generated, income from the household etc. and gave the conclusion of separation of infectious waste is important for the total solid waste. Income or the treatment cost decides the quantity of treated and untreated infectious waste. If waste is handled properly by the municipalities or the hospital, then the income is used as investment the life expectancy that can be increased. There is a direct relation of non-handling of waste to the human health risks. In another study, in 2012, Ciplak and Barton (2012) analyzed waste segregation relation to the cost of treatment of waste by Vensim software. They discussed about the management of waste related to the healthcare in Turkey by categorizing the waste as: municipal, hazardous and healthcare, they identified incineration or other treatment method which can be decided by segregation efficiency of waste. The simulation result of the model has given an estimation of thirty percent reduction of municipal waste could reduce 8000 tons of healthcare waste every year by 2025 and the value of reduction in healthcare waste could be 10000 tons per year by 2035. Nesli Ciplak (2013) have studied about the bad effects over workers of managing the healthcare waste on landfill sites and the incineration sites with the help of system dynamics modeling. It specifically defines the term “Emission Pathway Receptor” by using Vensim for Istanbul, Turkey. Daily cough and the skin diseases have been observed as the common symptoms among all the workers due to emission of harmful greenhouse gases over the waste treatment sites and because of inhaling the polluted air, drinking bad water and contamination of food with various hazardous metals. The employees who are working on the landfill sites or the incineration sites suffer from various diseases related to respiration, heart, lung or even cancer. Over the same period of employment among all the workers the mortality rate is higher in incinerators than landfills. In the Manipal University, Manipal, India, a study was conducted on the effect of waste generation due to urbanization by Pai et al. (2014). They used system dynamics modelling with Vensim software to find the quantitative changes in waste development due to an increase of population density caused by immigration. It also concerns about the policies that could be used to spread awareness among people to avoid health problems and to create sustainable waste management system by reducing the waste. Their focus was only on the domestic and hospital waste. This might be one of the limitation of this work. A system dynamic model using iThink software has been developed for the management of hospital waste in 2016 by Issam et al. (2016) in Nablus Palestine. Waste was categorized there into two types: general and hazardous from different private, government and charitable hospital. The difference has been observed in the values of hazardous to non-hazardous waste due to the difference of rules and regulations and classification of waste among the three types of hospitals. With growing population, waste generation has increased and thus there is increase in the untreated waste or hazardous waste that could further increase the health risks by contaminating the nature. This model studied a time period of twenty years thus giving an idea to the planners and the policy makers to protect the human health and environment by calculating the total hospital waste and total general waste. The other idea has been given to future research that may include other variables such as influence of Gross Domestic Product, waste generation per patient etc.

2.2.8. Recycling of civil-construction materials reduces waste management cost effectively

Using the policy and economy option Zhao et al. (2011) developed a model by using Vensim software for evaluation of alternative types of recycling center for the waste of construction and demolition produced in Chongqing region of China in 2011. By considering different indicators and factors, they concluded economic feasibility of the recycling centers and ratio of saving to cost in C&D waste management can increase collection of extra revenue from location advantage (of recycling center) as a profit. In 2014, Calvo et al. (2014) have developed a system dynamic model with socio economical implication of waste management using Vensim software. The study was based on the concept of "Extended Producer Responsibility" that promotes the demand for recycling and improves the effectiveness of waste management. Here, the policies were based on economic incentives and the tax penalties for the construction and demolition waste management in Spain. For the fulfillment of the objectives a term "Environmental Management System" was introduced. The focus was on eliminating the illegal landfills, valorization of inert waste and the demand for the construction and demolition wastes. China has the problem for management of construction and demolition waste. In 2016, Ding et al. (2016) made one system dynamics model with Vensim software to reduce the waste from the source of production which can reduce the total amount of generated waste. This model explained about the separation of waste that can improve the recycling process and the reuse efficiency of the waste. The reuse and recycling efficiency can further improve the land water loss as by decreasing the landfill pressure. Moreover, it also saves the land resources by decreasing the number of landfill sites. The other benefit is the reduction in the cost of waste management by controlling illegal dumping of waste, by on-site management of waste and by following government policies. In the year of 2016, Sukholthaman and Sharp (2016) have studied the separation effect of solid waste in the developing country Bangkok, Thailand to the final disposal of municipal solid waste by studying the different scenarios with the help of system dynamics software Vensim. The model has used six scenarios and among all the scenario with high separation rate of municipal solid waste by the involvement of the public has been chosen as the best efficient case to avoid the extra money over the disposal of solid waste and moreover to extend the landfill life.

2.2.9. Recycling of waste products could be a profitable business

A recent study in 2017 was conducted about the municipal solid waste management in the city of Tehran, Iran by Zanjani et al. (2012). A system dynamics model using Vensim software was developed to study the relation between the separation and the generation of waste (Saeedi et al., 2012). The effect of population was described as an indirect variable for the production of waste. The other policies and the variables have also been studied and interconnected such as recycling system, public concern, sanitary landfill, per capita income etc. They described that there is a direct relation between the dumping of waste and sanitary landfills by the government with the loans that are taken by the government for their countries from the other countries of the world for the desirable waste management policies. These policies encourage people to separate the waste. Recycling has been defined as another important variable by naming it as "Black Gold". The recyclable and the bi-products could possess profit to economy, as renewable source of energy is a prime field of study in current perspective with huge economic benefits. Thus by making the waste useful and beneficial, it increases the value of discarded waste to many folds.

3. Discussion

As per the discussion of different roles of SDM in the SWM it has been found that this strategy based studies could ease the work-load and reduce the errors in future by considering the important parameters. The population has been defined as the most important parameter among various researches. The change in population density due to various reasons may affect/ increase the generation of waste and hence the disposal of waste to the landfill which is the ending step of waste management. Moreover, we included the study of different models with almost each possible scenario related to the waste management with the socio-economic, environmental and technological aspects by interconnecting the different variables. Like in past, plenty of hazardous wastes were dumped of in regular landfills, resulting in abundant amounts of hazardous materials leaking into the ground. They eventually entered to natural hydrologic systems and contaminating groundwater (El-Fadel et al., 1997). Due to this, recently barriers have installed along the foundation of the landfill to prevent the hazardous substances from seeking out. Moreover, many steps has been taken, like, hazardous wastes must be stabilized and/ or solidified in order to enter a landfill and also must undergo different treatment protocols in order to stabilize and dispose them (Wiles, 1987). Here, recycling has conducted to make the most flammable materials into industrial fuel. Moreover, other hazardous wastes like, lead-acid batteries or electronic circuit boards can be recycled. When heavy metals in these types of ashes go through the proper treatment, they could bind to other pollutants and convert them into easier-to-dispose solids. Such treatments reduce the level of threat of harmful chemicals. So, the importance of recycling of waste materials remains one of the main approaches to reduce the toxicity and also to re-use the by-products as fuel for the industry and construction materials.

The SWM recently has been categorized by the help of SD to make the process easier into four different parts, i.e., domestic solid waste, industrial solid waste, agricultural solid waste and hazardous waste. The further categorization also may have been done in the development of system dynamics model by dividing the system into three parts: waste discharge system, waste disposal system and waste administration system. The further addition of variables to each system and the simulation run of the model have found a relationship between the population, waste and the economy of country. The selection of methods for the disposal of waste and discharge of waste can affect the economy of any region. The growing population and the development have many issues to consider. Due to economic development life style of people are changing. Due to increasing working female population in all the countries reduction in kitchen waste is compensating by the restaurant waste. But the industrial waste for the manufacturing of products for the population with increasing life style is not compensating with other variable. Infrastructural development, urbanization and deforestation are giving rise to problems related to environmental safety. Thus, the generation of waste needs to be treated or managed properly to avoid the health issues or environmental pollution. The work with socio-economic, environmental and technologic variables of modeling has been explained above. The other variables that can be included to the study of waste management are to relate the waste management with the climate change scenario. Due to leachate production, groundwater contaminates and thus can lead to various human health problems if it will be directly used for drinking. These health issues can be resulted into increase of hospital waste and thus follow the same cycle for hospital waste management with system dynamics (Abd El-Salam et al., 2015). The emission of methane or greenhouse gases from reduction of waste by landfills can result into various other issues like climate change due to change in the precipitation, change in weather conditions etc. The increase of gases in the environment can lead to other problems related to health and environment. Therefore, with the changing population and the economic growth, the awareness among people about the problems in climate change and as well about the systems related to these problems is required. Now, the people are being encouraged to work in this field to find the relation among different variables. Other than the consideration of conventional issues, the requirement is to consider the novel parameters related to this field.

Apart from the conventional studies, a plenty of factors could be taken into consideration in future to construct ideas in more realistic manners. Here, some of them are put forward, as like, (1) the research on the emission of methane from the landfill sites requires special attention to combat the environmental problems. The importance of this type of study will hold key for the problem of temperature rise due to the emission of methane or other greenhouse gases, further can be related to the variable "change in precipitation" and thus change in the natural hydrological cycle. (2) a proper education for the mass-population, specially, to the women should take care of; as we know female plays a big role in everyday life, as they are the "queen of the kitchen". If female population is educated, then they can help to spread the knowledge of waste management to their children and thus the sorting of waste will be easier in coming days. If female is working in any company, then the restaurant food waste could replace waste production in the kitchen. Hence, the variables that could be used in other model are as follows: waste generation, female population, waste separation, educated population, educated female population, working female population etc. (3) the disposal of waste to the landfill sites ends up in the emission of greenhouse gases and leachate production. Production of leachate deteriorates the groundwater that can result into bad health of human. The greenhouse gases result into the increase of temperature in the environment and thus can affect climate, rain etc. and ultimately an affect the population by affecting the health.

4. Conclusion

Thereby, the cream of every model can be summarized in as by three systems: waste management system, waste discharge system and waste disposal system. The simulation run of each system dynamics model of solid waste management has ended up with different results related to the variables used in the model. From this review, we can conclude that system dynamics is one the best possible way to find quantitative and qualitative relation between the different variables of waste management to avoid the further environmental, social, technological, and economical problems. Thus, the involvement of system dynamics in management of waste system should be more often to ease down the processing by considering the important parameters.

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REFERENCES

Al-Khatib, I. A., Eleyan, D., Garfield, J., 2016, A System dynamics approach for hospital waste management in a city in a developing country: The case of Nablus, Palestine, Environmental Monitoring and Assessment, 188(9), 503.

Apostolos, G., Chen, M., Yin, K., Veksha, A., 2017, Application of system dynamics modeling for evaluation of different recycling scenarios in Singapore, Journal of Material Cycles and Waste Management, 19(3), 1177-1185.

Bufoni, A. L., 2017, Modeling trends in solid and hazardous waste managementm In: Sengupta, D., Agrahari, S. (eds.), Modelling Trends in Solid and Hazardous Waste Management, Springer, Singapore, 141-157.

Chalupsky, H., MacGregor, R. M., 1999, STELLA - A Lisp-like language for symbolic programming with delivery in common lisp, C++ and Java, In Proceedings of the 1999 Lisp User Group Meeting, Berkeley, CA, Franz Inc., 1-8.

Chifari, R., Piano, S. L., Matsumoto, S., Tasaki, T., 2017, Does recyclable separation reduce the cost of municipal waste management in Japan, Waste Management, 60, 32-41.

Dace, E., Bazbauers, G., Berzina, A., Davidsen, P. I., 2014, System dynamics model for analyzing effects of eco-design policy on packaging waste management system, resources, Conservation and Recycling, 87, 175-190.

Dege, N., 2011, Technology of bottled water, (Third edition), Blackwell Publishing Ltd., Oxford, UK.

Dewki, L., 2014, Solid waste management in the town of darjeeling: Environmental concern, International Journal of Humanities and Social Science Invention, 3(6), 26-34.

Ding, Z., Yi, G., Tam, V. W. Y., Huang, T., 2016, A System dynamics-based environmental performance simulation of construction waste reduction management in China, Waste Management, 51, 130-141.

Dodds, F., Schneeberger, K., Ullah, F., 2012, Review of implementation of agenda 21 and the rio principles, report SD21, Sustainable Development in the 21st century (SD21), New York, USA.

Du, M., Peng, C., Wang, X., Chen, H., Wang, M., Zhu, Q., 2017, Quantification of methane emissions from municipal solid waste landfills in China during the past decade, Renewable and Sustainable Energy Reviews, 78, 272-279.

Dyson, B., Chang, N. B., 2005, Forecasting municipal solid waste generation in a fast-growing urban region with system dynamics modeling, Waste Management, 25(7), 669-679.

El-Fadel, M., Findikakis, A. N., Leckie, J. O., 1997, Environmental impacts of solid waste landfilling, Journal of Environmental Management, 50(1), 1-25.

El-Salam, A., Magda, M., Gaber, I. A., 2015, Impact of landfill leachate on the groundwater quality: A Case study in Egypt, Journal of Advanced Research, 6(4), 579-586.

Fang, S., Yu, Z., Lin, Y., Lin, Y., Fan, Y., Liao, Y., Ma, X., 2017, A Study on experimental characteristic of co-pyrolysis of municipal solid waste and paper mill sludge with additives, Applied Thermal Engineering, 111, 292-300.

Forrester, J. W., 1994, System dynamics, systems thinking, and soft OR, System Dynamics Review, 10(2-3), 245-256.

Hamsah, M. S., Burhanuddin, S., Harianto, T., 2016, Dynamic delphi multi criteria based analysis for collaborative solid waste management decision making in Baubau municipality, Indonesia, International Journal of Engineering Research & Technology, 5, 820-829.

Hao, J. L., Hills, M. J., Huang, T., 2007, A Simulation model using system dynamic method for construction and demolition waste management in Hong Kong, Construction Innovation, 7(1), 7-21.

Homer, J., Gary, B., Hirsch, B., 2006, System dynamics modeling for public health: Background and opportunities, American Journal of Public Health, 96(3), 452-458.

Hongyun, H., Zhang, Z., Xia, S., 2016, The crowding-out effects of garbage fees and voluntary source separation programs on waste reduction: Evidence from China, Sustainability (Switzerland), 8, 678-695.

Islam, K. M. N., 2017, Municipal solid waste to energy generation: An Approach for enhancing climate co-benefits in the urban areas of Bangladesh, Renewable and Sustainable Energy Reviews, 6, 53.

Joakim, K., Eklund, M., 2010, Developing a monitoring method facilitating continual improvements in the sorting of waste at recycling centres, Waste Management, 30(1), 32-40.

Karavezyris, V., Timpe, K. P., Marzi, R., 2002, Application of system dynamics and fuzzy logic to forecasting of municipal solid waste, Mathematics and Computers in Simulation, 60(3), 149-158.

Kollikkathara, N., Feng, H., Yu, D., 2010, A System dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues, Waste Management, 30(11), 2194-2203.

Kum, V., Sharp, A., Harnpornchai, N., 2005, A System dynamics study of solid waste recovery policies in Phnom Penh City, In: Proceeding of the 23rd International Conference of the System Dynamics Society, Boston, MA (CD-ROM version).

Long, B., 2004, iModeller 3D Professional 2.0, Macworld, 21(9), 35.

Maheshwar, D., Mittal, R. K., 2010, Future trends in computer waste generation in India, Waste Management, 30(11), 2265-2277.

Marshall, R. E., Farahbakhsh, K., 2013, Systems approaches to integrated solid waste management in developing countries, Waste Management, 33(4), 988-1003.

Mcallister, J., 2015, Factors influencing solid-waste management in the developing world, Master of Science (MS) Dissertation, Utah State University, USA.

Mochammad, C., Tanaka, M., Shekdar, A. V., 2008, A System dynamics approach for hospital waste management, Waste Management, 28(2), 442-449.

Moh, C. Y., Manaf, L. A., 2017, Solid waste management transformation and future challenges of source separation and recycling practice in Malaysia, Resources, Conservation and Recycling, 116, 1-14.

Mohammad, A., 2014, Barriers of commercial power generation using biomass gasification gas: A Review, Renewable and Sustainable Energy Reviews, 29, 201-215.

Mohammed, K. S., 2012, The importance of recycling in solid waste management, Macromolecular Symposia, 320(1), 43-49.

Mombelli, D., Mapelli, C., Barella, S., Gruttadauria, A., Landro, U. D., 2015, Laboratory investigation of waelz slag stabilization, Process Safety and Environmental Protection, 94, 227-238.

Moyano, M., Ignacio, J., Richardson, G. P., 2013, Best practices in system dynamics modeling, System Dynamics Review, 29(2), 102-123.

Nassar, U. A., 2017, Expansion of the prophet mosque as a catalyst for sustainable urban development in Al-Madinah Almunawarah in Saudi Arabia, 2(1), 99-115.

Nesli, C., 2013, A System dynamics approach for the determination of adverse health impacts of healthcare waste incinerators and landfill sites on employees, Environmental Management and Sustainable Development, 2(2), 7-28.

Nesli, C., Barton, J. R., 2012, A System dynamics approach for healthcare waste management: A Case study in Istanbul metropolitan city, Turkey, Waste Management & Research, 30(6), 576-586.

Nuria, C., Candamio, L. V., Corti, I. N., 2014, A Dynamic model for construction and demolition (C&D) waste management in Spain: Driving policies based on economic incentives and tax penalties, Sustainability, 6(1), 416-435.

Ojoawo, S. O., Agbede, O. A., Sangodoyin, A. Y., 2012, System dynamics modeling of dumpsite leachate control in Ogbomosoland, Nigeria, Journal of Environmental Protection, 3(1), 120-128.

Pai, R. R., Rodrigues, L. L. R., Mathew, A. O., Hebbar, S., 2014, Impact of urbanization on municipal solid waste management: A System dynamics approach, International Journal of Renewable Energy and Environmental Engineering, 2(1), 31-37.

Parate, M. U., Shinde, R., 2016, Transportation management in Pune City, International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), 2(4), 166-169.

Pires, A., Martinho, G., Chang, N. B., 2011, Solid waste management in European countries: A Review of systems analysis techniques, Journal of Environ -mental Management, 92(4), 1033-1050.

Pomberger, R., Sarc, R., Lorber, K. E., 2017, Dynamic visualisation of municipal waste management performance in the EU using ternary diagram method, Waste Management, 61, 558-571.

Pubule, J., Blumberga, A., Romagnoli, F., Blumberga, D., 2015, Finding an optimal solution for biowaste management in the Baltic States, Journal of Cleaner Production, 88, 214-223.

Robert, G., Marcin, P., Marek, M., 2017, Analysis of picked up fraction changes on the process of manual waste sorting, Procedia Engineering, 178, 349-358.

Sabo, H. B., Haruna, M., 2015, Environmental strategy and management in the speed of change: A Study of recycling approach as valuable lesson for Africans, 5(1).

Schiopu, A. M., Ghinea, C., 2013, Municipal solid waste management and treatment of effluents resulting from their landfilling, Environmental Engineering and Management Journal, 12(8), 1699-1719.

Scott, F. R., 2014, Insight maker: A General-purpose tool for web-based modeling & simulation, Simulation Modelling Practice and Theory, 47, 28-45.

Shukla, R., 2016, Review article - Smart waste management, Asian Journal of Pharmaceutical Education and Research, 5(2), 48-54.

Sitarz, D., 1993, The earth summit strategy to save our planet, United States: Boulder, CO (United States), EarthPress.

Sterman, J. D., 2001, System dynamics modeling: Tools for learning in a complex world, California Management Review, 43(4), 8-25.

Sufian, M. A., Bala, B. K., 2007, Modeling of urban solid waste management system: The case of Dhaka city, waste management, 27(7), 858-868.

Sukholthaman, P., Sharp, A., 2016, A System dynamics model to evaluate effects of source separation of municipal solid waste management: A Case of Bangkok, Thailand, Waste Management, 52, 50-61.

Sumari, S., Ibrahim, R., 2013, Comparing three simulation model using taxonomy: System dynamic simulation, discrete event simulation and agent based simulation, International Journal of Management Excellence, 1(3), 4-9.

Tackett, T., Jacobs, D., Carlstad, C., Riverson, J., 2013, Evaluating and implementing Seattle's green stormwater infrastructure approaches at a creek watershed scale, Proceedings of the Water Environment Federation, 9, 6017-6041.

Talyan, V., Dahiya, R. P., Anand, S., Sreekrishnan, T. R., 2007, Quantification of methane emission from municipal solid waste disposal in Delhi, Resources, Conservation and Recycling, 50(3), 240-259.

Tisue, S., Wilensky, U., 2004, NetLogo: A Simple environment for modeling complexity, 1-10.

Ventana Simulation Environment - User's Guide Version 6, 2016, http://vensim.com/docs/

Vinkenburg, C. J., 2017, Engaging gatekeepers, optimizing decision making, and mitigating bias: Design specifications for systemic diversity interventions, The Journal of Applied Behavioral Science, 53(2), 212-234.

Wahid, S. S., 2012, Assessment of physiochemical properties for hazardous (biomedical) waste categories: A Case study in 'hospitals of Minia governorate cities, Egypt', 31(2).

Wahid, S. S., Governorate, M., 2013, Design criteria for the hazardous (biomedical) waste incineration plants for hospitals, 32(1).

Wang, Y., Cheng, K., Weidong, W., Tian, H., Yi, P., Zhi, G., Fan, J., Liu, S., 2017, Atmospheric emissions of typical toxic heavy metals from open burning of municipal solid waste in China, Atmospheric Environment, 152, 6-15.

Wiles, C. C., 1987, A Review of solidification/ stabilization technology, Journal of Hazardous Materials, 14(1), 5-21.

Yuan, H., Wang, J., 2014, A System dynamics model for determining the waste disposal charging fee in construction, European Journal of Operational Research, 237(3), 988-996.

Zanjani, A. J., Saeedi, M., Kiani, B., Vosoogh, A., 2012, The effect of the waste separation policy in municipal solid waste management using the system dynamic approach, International Journal of Environmental Health Engineering, Medknow Publications & Media Pvt. Ltd., 1(1), 1-5.

Zhang, H., Liu, J., Wen, Z., Chen, Y. X., 2017, College students' municipal solid waste source separation behavior and its influential factors: A Case study in Beijing, China, Journal of Cleaner Production, 164, 444-454.

Zhao, R., Xi, B., Liu, Y., Su, J., Liu, S., 2017, Economic potential of leachate evaporation by using landfill gas: A System dynamics approach, Resources, Conservation and Recycling, 124, 74-84.

Zhao, W., Ren, H., Rotter, V. S., 2011, A System dynamics model for evaluating the alternative of type in construction and demolition waste recycling center – The case of Chongqing, China, Resources, Conservation and Recycling, 55(11), 933-944.

Zhuang, Y., Wu, S. W., Wang, Y. L., Wu, W. X., Chen, Y. X., 2008, Source separation of household waste: A Case study in China, Waste Management, New York, 28(10), 2022-2030.