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Research Article

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Framework for Low Carbon Precinct Design from a Zero Waste Approach

Queena K Qian[1]*, Steffen Lehmann[2], Atiq Uz Zaman[3] and John Devlin[3]

[1]*Endeavour Australian Cheung Kong Post-Doc Fellow, sd+b Centre, University of South Australia, Australia*
[2]*Chair Professor of Sustainable Design; Director, sd+b Centre and CAC-SUD Centre, University of South Australia, Australia*
[3]*PhD Candidate, sd+b Centre, University of South Australia, Australia*

Abstract

The consumption-driven society today produces an enormous amount of waste, which puts pressures on land, pollutes the environment and creates economic burden. 'Zero waste' concept, a whole system approach aiming to achieve no waste along the materials flow through society, has become one of the most visionary concepts for tackling growing waste problems. System Dynamics (SD) approach is applied in the proposed framework for designing the waste management in a zero waste residential precinct. A cost-benefit analysis (CBA) is incorporated to supplement the SD framework to evaluate the total cost and benefit of waste and resources throughout the material flow chain. The authors proposed a list of parameters under the categories of process, technology and infrastructure, socio-economic and institutional, social- environment, to be tested in future case study of Bowden village, SA, Australia. The framework provides an inventory of leverage points that helps policy-makers design waste policies and allocate resources effectively, with minimum environmental impact and optimum social benefits. It also helps planning professionals and business stakeholders better understand the costs and benefits of different scenarios for achieving a zero waste residential precinct.

Keywords: Cost-benefit analysis; Low-carbon residential precinct; Solid waste management; System dynamics; Zero waste

Introduction

The development of science and technology as well as global levels of economic activity causes a dramatic increase in the production of urban solid waste [1]. The generation of waste over time has become a serious environmental problem for the world, and been affecting the balance of natural resources [2]. Solid Waste Management (SWM) has become crucial for protecting the environment and the human well-being. Various national and international initiatives for SWM are in place, which takes considerations of environmental, administrative, regulatory, scientific, market, technology, institutional and socio-economic factors [3].

The sustainable SWM is becoming essential at all phases of the waste chain from production, waste generation, collection, transportation, treatment, recycling till disposal. 'Zero waste' is, therefore, becoming a popular concept. It is a closed-loop concept aiming of optimum recycling or resource recovery, as well as elimination of unnecessary waste in the first place [4,5]. With a whole system approach, it seeks for an end–of-pipe solution for waste diversion along the materials flow through society. It encourages waste elimination through recycling and resource recovery, with a guiding design philosophy to reduce waste at source and at all points down the supply chain [6]. 'Zero waste' commitments have been made across the world, including US, Europe, Australia, New Zealand, etc. [7], and becomes trendy for the rest of the world.

A sustainable SWM approach is systematic, flexible and long term visionary. A sustainable society requires sophisticated ways to manage solid waste. A systems approach that reveals the relationships and explains its interactions among the parties in the system contributes to greater sustainable practice [8]. Based on reviewing and comparing different researchers' work on the waste management, our research aims to propose a research framework of zero-waste management and strategies for low carbon residential precincts. This approach selected needs to accommodate the fact that zero waste management can be achieved by identifying the leverage points during the entire zero waste chain and altering or redesigning the processes accordingly. Kytzia and Nathani believe a "combination between analyses of economic/physical structures on the one hand and economic behaviour on the other hand is most promising" to achieve the zero waste concept [9]. The methodological framework presented will contributes to the understanding of the overall process of the zero waste management by combining system characteristics as well as the cost/ benefit impact with the attitudes and requirements of a specific stakeholder group (i.e., the city planner, government, and/or households). This paper highlights the dynamic interrelationships of the sustainable SWM practices, supplemented with the cost/benefit factors into the SD process. The system-oriented research framework serves the decision-makers to draw the forward-looking and preventative insights and reach a scientific understanding of the carbon and cost consequences relating to various sustainable SWM scenarios.

Literature Review

Similar researchin SWMand system approach

Research interests in addressing waste management issues have resulted in a large amount of publications during the last decade. Ossenbruggen and Ossenbruggen apply SWAP programs - a linear programming algorithm, to aid in the strategic plan and decision-makings of SWM, and weigh the cost associated and the benefits from various waste recovery alternatives [10]. Chung and Poon has applied multiple criteria analysis (MCA) in SWM to find out the preferred

***Corresponding author:** Queena K Qian, Endeavour Australian Cheung Kong Post-Doc Fellow, sd+b Centre, University of South Australia, Australia, Tel: +852 56127050; E-mail: kun.qian@fulbrightmail.org

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waste management options. The merit of MCA is more objective and transparent and it accommodates quantitative and qualitative data [11]. Bovea et al. apply the Life Cycle Assessment technique to obtain parameters that quantifies the environmental impact of waste transportation and operating a transfer station in municipal SWM systems [12]. Beigl et al. review the modelling approaches for SWM and propose an implementation guideline with a compromise between information gain and cost-efficient model development [13]. Lu and Yuan develop a framework to understand the C and D WM research as archived in selected journals, and give useful references attempting the research of C and D WM research [14]. Chang and Davila simulate the predetermined scenarios with a minimax regret optimization, to achieve improved SWM strategies from different environmental, economic, legal, and social conditions [15].

Planning sustainable SWM has to address several interdependent issues including public health, the environmental impact, the treatment potential, the landfill capacity, and present and future economic and social costs, and financial expenditures, etc. It, therefore, becomes increasingly necessary to understand the dynamic nature of their interactions, and the complex, and multi-faceted system. How to combine all the correlated factors into the consideration when making the optimal sustainable SWM strategy among the alternatives? Pries et al. believes that system approach enriches the analytical framework of SWM, specially designed to understand the dynamics and intercalations among the factors, and develop better SWM strategies for both the SWM industry and the government [16]. It plays an important role to simulate and assess the integrated SWM systems, and inform the stakeholders with insightful strategies and rational decision-makings.

System dynamics (SD) approach in MSW management

SD is a well-established methodology that provides a theoretical framework and concepts for modelling complex social, economic and managerial systems [17]. It deals with the interrelationships and complex of the system, where the dynamic behaviour can be reflected and simulated by the feedback loops based on the control theory [18–21]. The SD approach is widely applied in the areas of environmental sustainability and regional sustainable development issues [22-26] environmental management and environmental systems [27,28], and waste management [29-31].

Thirumuthy applied SD approach to evaluate the investments required for various environmental services in Madras city [32]. Mashayekhi explored a dynamic analysis for analysing the transition from the landfill method of disposal to other forms of disposal for the city of New York [33]. Sudhir et al. proposed a system dynamics model to capture the dynamic nature of interactions among the various components in SWM for developing countries [28]. Karavezyris et al. studied the quantitative impact of different variables, such as voluntary recycling participation and regulation, on SWM [34]. Ulli-Beer presented a SD model for understanding local recycling systems [35]. Dyson and Chang applied a SD approach to predict solid waste generation in a fast growing urban area [36]. Duran et al. developed a model to assess the economic viability of creating markets for recycled construction and demolition (CandD) waste in scenarios using different economic instruments [37]. Rehan et al. proposes SD approach to develop a causal loop diagram for water and wastewater network management, as a complex system with multiple interconnections and feedback loops [38]. It demonstrates the significance of feedback loops for financial management of the complexity of the system by incorporating all feedback loops. Yuan et al. proposes a SD model to serve as a decision support tool for waste projection, and as a platform for simulating effects of various waste reduction management strategies [39].

A sustainable SWM system incorporates feedback loops, focusing on processes, embodies adaptability and diverts wastes from disposal [8]. Due to the SWM hierarchy, the challenges lie in how to diversify the waste reduction options, increase the reliability of infrastructure systems, and leverage the redistribution of waste streams among production, transportation, compost, recycling, and other facilities. It depends on factors such as technology and infrastructure, socio-economic and institutional, social- environment, culture, as well as market considerations [40,41]. Transitioning to a sustainable SWM system requires identification and application of leverage points that stimulate positive change [8]. SD approach recognizes the sustainable SWM process and accommodates the zero waste achievement by identifying the leverage points during the entire zero waste chain and altering or redesigning the processes accordingly.

Cost-Benefit Analysis (CBA) supplemented in SD

Economic instruments to minimize waste play a crucial role in encouraging environmentally-friendly SWM practices [30]. The rising pressure in terms of cost efficiency on public services and facilities pushes governments to share those services with the industry. The partnership among the government, business and individual household collectively contributes to the overall effectiveness and efficiency of the MSW management. Therefore, CBA of waste management are essential to provide the evidence that will motivate stakeholders throughout waste management chains, and SD modelling helps examine the relationships between waste management activities in a holistic view. Yuan et al. analysed the CBA of the dynamics and interrelationships of CandD waste management practices using a SD approach [30]. Farel et al. proposes a SD approach to simulate the net economic balance of the recycling network under different future scenarios [42]. Therefore, a good balance between the cost and benefits is an important factor to select among the scenarios for the use of different stakeholders.

CBA has been widely acknowledged as a tool for policy and project analysis throughout the world. It helps the policy-makers as well as stakeholders to justify their decisions in a more systematic, rigorous and unambiguous way Gramlich [43]. It allows us to identify and assess positive and negative economic and physical effects independently. Particularly, it supports the simulation and optimization models for system analysis. Well-defined CBA parameters may translate environmental aspects into economic terms.

Methodological Framework

The life cycle of zero- waste in diagram (Figure 1)

The waste management chain consists of a series of potential lifecycle stages. Products pass through the manufacturing, production, and consumption stages before entering into the waste management system where various processes can minimize the impact of the waste. It is not a collection of independent waste management activities but rather a system of interdependent activities. It is to put together all the potential acts to reduce the original waste to be generated, until the waste can finally be disposed of with minimum costs involved. Some typical factors affecting waste management activities are based on an extensive literature review as well as works previously carried out at the zero waste research centre [4].

System dynamics (SD) approach-Causal loop SD diagram for a zero-waste precinct

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This causal loop diagram is designed based on the interaction of different components in a zero waste management system. It identifies the carbon emission loops and external factors as well as interrelationships in SWM from waste generation (manufacture, household consumption, separation) to collection, treatment, recycling and disposal. This study frames the scope of the zero-waste loop and establishes the initial step of a SD study framework. It is used to identify and explain the causal relationships between acts and stages of waste management in a residential precinct. Based on the above extensive literature reviews on SD and conceptual model of the zero-waste management chain in low carbon residential precinct (Figure 1), the causal loop diagram of zero-waste precincts can be developed (Figure 2).

Cost benefit analysis (CBA) approach

CBA is an analytical procedure to evaluate the desirability of a program or project by weighing the resulting benefits against the corresponding costs in order to see whether the benefits outweigh the costs [44-46]. In this research, CBA consider sand reflects the tangible factors (such as environmental costs) as well as invisible benefits, from the improved SWM scenarios. It attempts to evaluate effects on users (policy-makers as well as stakeholders), external effects, quantify values and social benefits. In this research, the current value of a collective SWM scenario is considered on a net present value (NPV) basis. NPV reflects a stream of current and future benefits and costs, and results in a value in today's dollars that represents the present value of an investment's future financial benefits minus any initial investment. Typically, financial benefits for individual elements are calculated on a present value basis and then combined in the conclusion with net costs to arrive to NPV, as the function below:

$$\mathrm{NPV} = \sum_{i=1}^{n} \frac{\mathrm{values}_i}{(1+\mathrm{rate}^i)}$$

If positive, the investment should be made, otherwise not. The value of the NPV of the proposed scenario gives a foundation for comparing alternative options. A bigger NPV indicates a better option.

Of particular interest to both waste industry stakeholders and policy-makers, this research looks into both private cost-benefit ratios (to establish how much benefit can be derived from every dollar is spent for improving waste management) and social cost benefit ratios (as the amount of return is perceived to have a direct impact on the degree of success of the waste management regulation or incentive scheme). The

Category	Parameters	-	+
Process	• Waste generation rate / Average waste generation per household /Waste generation after adopting waste reduction measures		×
	• Cost of waste collection		×
	• Recycling waste /cost of waste recycling / ratio of recycling		×
	• waste disposal cost / disposal cost saving / illegal disposal		×
	• transportation costs / transportation cost saving		×
	• Cost of waste sorting /ratio of reuse / cost of waste reuse / purchasing cost saving		×
	• Impact of landfill space limit on waste reduction /Promotion of waste reduction via landfill charge/ Unit land filling charge fee		×
	• Waste reduction rate/ Amount of reduced waste /Efforts to reduce waste /Impact of waste reduction costs		×
	• Management capacity for reducing waste		×
Technology & Infrastructure	• Actual investment in waste management (increasing rate)		×
	• Low-waste technologies application		×
	• Frequency of technology changes/updates		×
	• Training in waste management		×
	• Actual industry stakeholders' initiative to minimize the waste		
	• Changing of investment in waste management / Impacts of technology changes on waste reduction		×
	• Impact of measures taken for product design to reduce waste/ Decreasing of design changes		
Socio-economic, Institutional	• Regulation changes to SWM		×
	• Social performance value		
	• Regulating the illegal waste disposal to improve the society image		×
	• Public satisfaction of the waste performance		
	• Gaining experience of managing waste		
	• Impact of public's willingness to reduce waste / Changing of public's willingness		
	• Expected increasing rate of public's willingness to reduce waste		
by incentives		×	
	• Zero waste awareness and skills / Actual household's initiative to minimize waste		
	• Industry's willingness to reduce waste		
	• Improvements on SWM culture and public behaviour in the society		
	• Provision of job opportunities in waste management / Weight of provision of job opportunities		
Socio-environment	• Incentive to manage waste		×
	• Public appeal for zero waste to improve the environment		×
	• Environmental awareness / Environmental behaviour		
	• Accumulated environmental impact of zero waste to the environment		×
	• Accumulated impacts of physical living environment of SWM		
	• Impacts of SWM on participants' long-term health		
	• Accumulated performance value of waste emission		×
	• Weight of public's long-term health conditions		

Table 1: Selection of SD waste management Parameters for CBA ("-": cost; "+": benefit).

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amount of investment return of implementing a particular measure is evaluated using private benefit cost ratios. The mathematical function of adopting incentives can be obtained as following:

$$private\ cost\text{ - }benefit\ ratio_i^1 = \frac{\Delta B_i^{Econ}}{\Delta C_i^{Econ}}$$

Where ΔB_i^{Econ} and ΔC_i^{Econ} are the additional benefit derived, and additional life-cycle cost required for the private industry stakeholders and/or household by implementing the proposed waste management project or incentives, respectively. The private benefit–cost ratio can help identify which options are financially beneficial. The ratio can give an indication for selecting a particular measure if the ratio of the present value of benefits to the present value of costs is greater than 1.0.

$$social\ cost\text{ - }benefit\ ratio_i^1 = \frac{\Delta B_i^{Sco}}{\Delta C_i^{Sco}}$$

Where ΔB_i^{Soc} is the net benefit in monetary value derived for society by implementing the proposed improvement measure; ΔC_i^{Soc}, which is the additional life-cycle cost required by implementing the proposed incentives. The social benefit–cost ratio can assist government officials or policy-makers in judging the environmental viability of the measure under consideration.

Discussions and Findings

Table 1 lists the selection of SD waste management parameters base on the zero-waste casual loop diagrams (Figures 1 and 2), to be considered in CBA. All the parameters selected are based on the literature review and methodological framework done in the earlier session. They are assigned in the categories of Process, Technology and Infrastructure, Socio-economic, Institutional, and Socio-environment. All the parameters are assigned to be either under the cost (-) or benefit (+) or both, depending on whether they are mainly involving the costs or benefits, or both to the stakeholders along the SWM process. Very often, the parameters selected involve both costs and benefits depending on the different stakeholders.

The benefits to get CBA supplemented to the SD approach, in that it quantifies the potential returns and expenses of a program or project and balances the pros and cons to arrive at a decision. This line of research has important implications both for assessing the cost of correcting market failures – such as environmental externalities – as well as clarifying the role of policies that are oriented to correct behavioural failures and market barriers. The benefits and costs are usually quantified in real monetary terms, i.e. converted to the present value, to enable assessment of different the benefits and the costs over time. The major CBA indicators include present value, net present

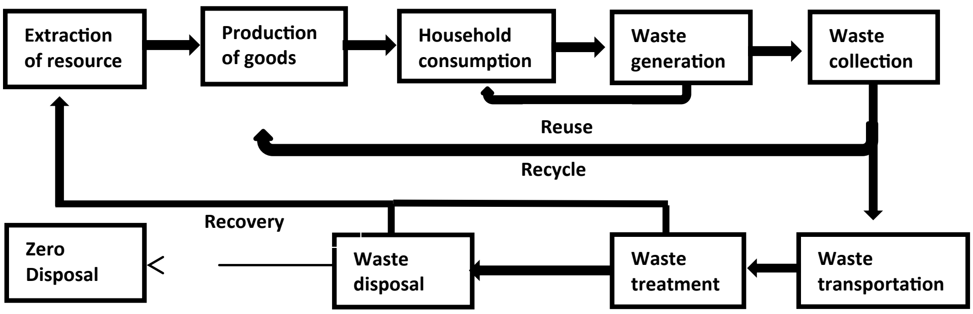

Figure 1: A conceptual model of zero-waste management chain for residential precinct.

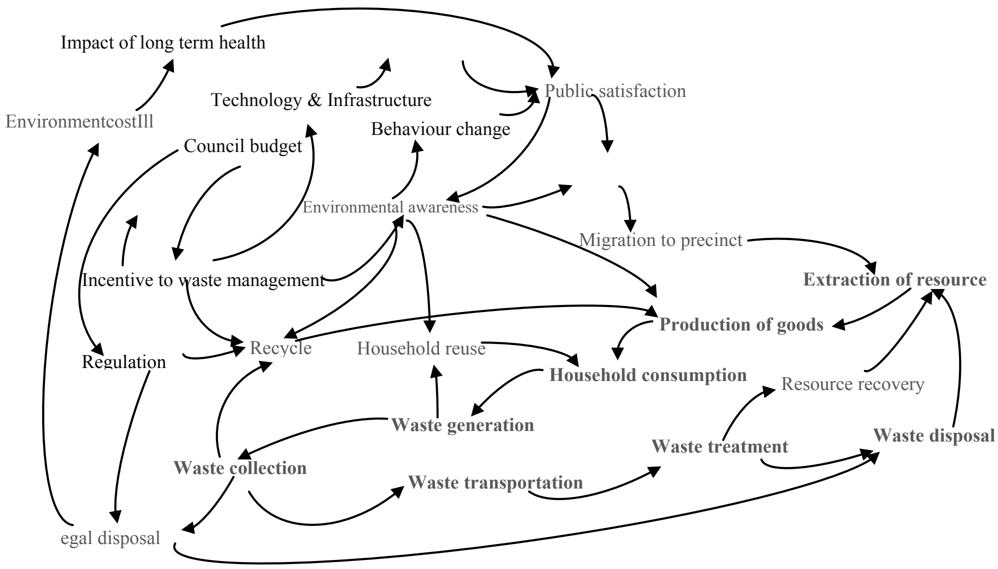

Figure 2: Causal loop SD diagram for a zero-waste precinct.

value and benefit cost ratio, which are applied in this study [47]. One of the aspects evaluated by CBA in this study is the hidden costs and benefits during the waste management loop, which has not been widely considered.

Future studies: scenarios setting and data collections- case of Bowden village, SA, Australia.

The framework proposed is to be tested in future study using real-life data, in three different residential density scenarios – mixed use high rise (10-storey), low rise (3 to 8-storey) and town house scale (3-storey). The data will be derived from Bowden Urban Village, a new residential precinct in Adelaide, the capital city of South Australia. Upon successful testing of the SD model using the Bowden village in future case study, it will be adjustable to a wider application to assist decision-making in different precincts. Most of the research on MSW management is examining systems at the city or national level. There are many benefits to this study's use of the precinct level: precincts provide more flexibility and precision, it also allows the model to be closer to reality as the dynamics and external factors at the city and/or national level are too complicated to be modelled.

The model described above is a theoretical framework for examining MSW loop and its management system at precinct level. For the future study case of Bowden urban village, three scenarios are set for different options and desire of the development plan- mixed use high rise (10-story), low rise (3 to 8-story) and town house scale (3-story). Using the SD simulation program, e.g. i think, it will examine the potential ways to reduce municipal solid waste (MSW) throughout generation, collection till disposal and concludes with overall carbon consequences and reduction options.

Following the general research framework developed in this paper, it is to collect and evaluate a broad spectrum of costs and benefits with the available data and the data from the survey, and to develop reasonable net present value estimation for comparison of each decision-making scenario. System dynamics approach is applied to capture and frame the scope of the waste life cycle in order to forecast the costs and benefits of waste management options from beginning to end. The overarching purpose is to answer the question: "does it make financial and economic sense for a given stakeholder, with particular incentives, to implement these waste management options?"; which serves the ultimate aim of this study: to balance the financial and economic interests of the private sector and those of the whole society (and environment) with minimum environmental impact and optimum social benefits, on behalf of the urban policy-maker.

Conclusions

Based on an extensive literature review on waste management of system approach, this paper proposes a holistic methodological framework for designing a SWM system for a zero-waste low carbon residential precinct. This study attempts to employ both a SD approach, incorporated with a cost-benefit analysis to simulate the changes in various MSW management scenarios for different low-carbon precincts. The causal loop diagram made it easier to understand and identify the critical activities throughout the waste management chain, the essential stakeholders and also external factors such as financial incentives. The methodological framework considers a list of parameters under the categories of socio-economic, institutional, socio-environmental, infrastructure and technology, and process. The framework is designed in such a way that it can be adapted to other local conditions by changing the local parameters and data for whatever the regional case. In future studies, the proposed framework will be modelled using a computer program, i.e., i think, with a stock-flow diagram simulating different scenarios. The cost-benefit changes for each scenario are to provide rational options among the simulation plans for decision-makers, city planners and other stakeholders, and to help predict future waste management needs.

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