CHEMICAL ENGINEERING TRANSACTIONS

VOL. 94, 2022

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Yee Van Fan, Jiří J. Klemeš, Sandro Nižetić

ISBN 978-88-95608-93-8; **ISSN** 2283-9216

DOI: 10.3303/CET2294061

Application of DEMATEL for Barriers Analysis of Co-management of Urban Bio-wastes in Phnom Penh, Cambodia

Sychheng Meas[a], Fidero Kuok[b,*], Michael Angelo B. Promentilla[a,c]

[a]Department of Chemical Engineering, Gokongwei College of Engineering, De La Salle University, 2401 Taft Avenue, Malate, Manila 1004 Philippines, Philippines
[b]National Institute of Science, Technology and Innovation, Cambodia
[c]Center for Engineering and Sustainable Development Research, De La Salle University, Manila 1004, Philippines
kuok.fidero@misti.gov.kh

The rapid urbanization in major cities, e.g., Phnom Penh, Cambodia, increases the concern for the integrated waste management of municipal solid waste and sewage as a social responsibility toward the public welfare. While high-income countries are gearing toward integrating waste management into the circular economy, low-to-middle income countries are still facing various challenges ranging from infrastructure investment to societal acceptance. Despite all barriers, mining the potential opportunity from the circular economy framework in waste management in terms of nutrient recycling from bio-wastes such as food waste and human excreta is yet to be explored; the difficulty and complexity in co-managing the urban bio-wastes anchor in switching from linear to circular thinking. This study aims to understand the barriers to implementing such co-management of organic waste and human excreta in Phnom Penh, the capital city of Cambodia, using the Decision Making Trial and Evaluation Laboratory (DEMATEL) methodology. The results show that the lack of regulatory enforcement and implementation to control the illegal disposal of municipal solid waste and septage waste is the key cause barrier. The highly linked barrier is the lack of appropriate collection, storage, and treatment system for municipal solid waste and septage waste. Thus, this study could provide insights into developing actionable policy recommendations to solve the issue of waste management while achieving SDG goals and exploring the benefit of a circular economy in Cambodia.

1. Introduction

Rapid population growth and urbanization have put environmental stress attributed to poor sanitation and lack of proper solid waste management. In comparison to that of high-income countries, residents in the low-to-middle income countries, especially the urban poor are more severely impacted by unsustainably managed waste (Abdel-Shafy and Mansour, 2018). Without proper management, a large volume of municipal solid waste is disposed of day by day in an unplanned and open site and therefore leads to the potential contamination of groundwater in the long term and water bodies in the short term. Likewise, poor sanitation is also a threat to the health of water bodies. In such a case, and if proper mitigation is not provided, this expense to environmental and public health will drag the nation's development and progress toward sustainability. For the last decade, Cambodia has learned its development course and committed to better municipal solid waste management, for instance, the decentralization of waste collection companies (Seng et al., 2010); even though the innovative approach to waste management is yet to be explored. During the past 30 y, from the concept to implementation, the integrated waste management system from generation sources to disposal has been applied widely and adapted to the prevailing country condition (Nordone et al., 2009). However, this integrated approach is still limited to the linear economy where natural resources are manufactured into the product, used, and disposed of at landfills. Thus, mining the potentiality of the circular economy framework as an innovative approach for waste management in which the possibility of recycling nutrients from bio-wastes such as food waste and human excreta offers a promising solution. Moreover, this circular economy framework is expected to harmonize economic development regardless of resource scarcity and environmental conservation goals (Hysa et al., 2020). It is thus imperative to explore the co-management of urban bio-wastes

Paper Received: 17 May 2022; Revised: 06 June 2022; Accepted: 10 June 2022
Please cite this article as: Meas S., Kuok F., Promentilla M.A.B., 2022, Application of DEMATEL for Barriers Analysis of Co- management of Urban Bio-wastes in Phnom Penh ,Cambodia, Chemical Engineering Transactions, 94, 367-372 DOI:10.3303/CET2294061

within such a circular economy framework. Likewise, this study aims to understand the barriers to implementing such co-management of organic waste and human excreta in Phnom Penh, the capital city of Cambodia, using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology. So far, various decision-making methods, e.g., multi-criteria decision-making (MCDM), are employed to search for decisions satisfying a multitude of conflicting objectives (Gal et al., 1999), and yet DEMATEL is still one of the fastest progressed techniques with simplicity to solve complex and intertwined problem groups or influential barriers (Yazdi et al., 2020). Such an engaging analysis of the influential barrier with the majority consensus accepted can be used to develop an actionable policy recommendation to solve the issue of waste management while exploring the benefit of a circular economy in Cambodia. For example, this tool has been applied in the problem analysis of public-private partnerships for small and medium enterprises in Cambodia (Kuok and Promentilla, 2021).

2. Methodology

The DEMATEL method is widely used to analyze barriers and their interrelationship with the following step-by-step procedure (Asadi et al., 2022):

Step 1: Populate the direct relation matrix Z with the intensity of influence of one barrier over the other. The scale is a 5-point level from 0-4, using an integer scale of "no influence (0)," "low influence (1)," "medium influence (2)," "high influence (3)," and "very high influence (4)." Then, the rating Z_{ij} provided by an individual stakeholder k provides the entry to the intensity of influence of barrier i to barrier j, where all principal diagonal elements are equal to zero in matrix Z. By aggregating the l stakeholders' rating, the group direct-influence matrix can be obtained by using Eq(1).

$$Z_{ij} = \frac{1}{l}\sum_{k=1}^{l} Z_{ij}^{k}, i,j = 1,2,...,n \tag{1}$$

Step 2: Normalize the direct-influence matrix Z using Eq(2) and Eq(3).

$$X = \frac{Z}{s} \quad \text{where } x = [x_{ij}]_{n\times n} \tag{2}$$

Note that
$$s = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} z_{ij}, \max_{1\le i\le n} \sum_{i=1}^{n} z_{ij}\right) \tag{3}$$

Step 3:

Construct the total-influence matrix T. Using normalized direct-influence matrix X, $T = [T_{ij}]_{n\times n}$ can be computed by summing the direct effects and all of the indirect effects by using Eq(4).

$$T = X + X^2 + X^3 + ... + X^h = X(1 - X)^{-1} \text{ where } h\to\infty, \tag{4}$$

Step 4: Create the problematic causal map. First, compute the row sum and column sum of the total influence matrix as shown by using Eq(5) and Eq(6).

$$R = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, i,j = 1, 2,\dots, n \tag{5}$$

$$C = [c_j]_{n\times 1} = \left[\sum_{i=1}^{n} t_{ij}\right]_{n\times 1}, i,j = 1, 2,..., n \tag{6}$$

In the map, the horizontal axis vector (R+C) named "Prominence" shows the strength of influences that are given and received by the barrier. Prominence index (R+C) stands for the degree of the central role that the barrier plays in the system. On the other hand, the vertical axis vector (R-C) called "net relation index" shows the net effect that the factor contributes to the system. If $r_i - c_j$ is positive, then the barrier B_j has a net influence on the other barriers and can be grouped into a cause group; if $r_i - c_j$ is negative, then the barrier B_j is being influenced by the other factors on the whole and should be grouped into effect groups. A threshold is defined to filter out the minor influences in the total relation matrix and thus simplify the depiction of the causal relationship among barriers. For example, the threshold value can be obtained by averaging the entries in the total relation matrix. The inner dependency matrix is derived by eliminating entries lower than the threshold value in the total relation matrix. This means that only significant relationships are retained. The inner dependencies among all barriers were also plotted in the form of a chord graph with different thicknesses of the chord to elucidate the degree of influence between barriers and within the barrier itself (Martin, 2008). Chord diagram or Circos diagrams illustrates interactions among several entities and links in the form of a circle between the entities. The benefit of utilizing the chord diagrams is to describe the network flow. It can provide operators with situational awareness in a straightforward manner.

3. Results and discussion

To identify the barriers to implementing the co-management of organic waste and human excreta in Phnom Penh, the capital city of Cambodia, a literature review was done as summarized in Table 1. The validity of the barriers was then reviewed by thirteen experts from four sectors: Government Agencies (3 experts), Development Partners (5 experts), Academics (3 experts), and Private Companies (2 experts).

Table 1: Barriers to co-management of organic waste and human waste

Label	Barriers	References
B1	Lack of appropriate collection, storage, and treatment for septage waste and municipal solid waste	(Spoann et al., 2018)
B2	Lack of composting facilities for co-management of septage waste and municipal solid waste	(EuroCham, 2019)
B3	Lack of human resources in the field of waste management	(Spoann et al., 2018)
B4	Lack of cooperation and coordination between the responsible authorities for municipal solid waste and septage waste management	(Peal and Evans, 2015)
B5	Lack of regulatory enforcement and implementation to control the illegal disposal of municipal solid waste and septage waste	(Spoann et al., 2018)
B6	Lack of financial support for the co-management of septage waste and municipal solid waste	(Peal and Evans, 2015)
B7	Lack of public willingness to segregate the municipal mixed solid waste	(Bandith, 2019)
B8	Lack of public willingness to use bio-fertilizer from co-composting of municipal solid waste and septage waste	(Gwara et al., 2021)

Table 2 shows the Direct relation matrix (Z) obtained by getting the average rating of the 15 decision makers. After normalizing the matrix using Eq(2), the total relation matrix is computed using Eq(4). Tables 3 and 4 show the normalized direct relation matrix and total relation matrix. From the total relation matrix, the prominence indices and net relation indices of the barriers are computed as shown in Table 5. The higher the (R+C) value, the more prominent the barrier is. On the other hand, the sign of (R-C) value determines whether the barrier is the cause or the effect. Among all barriers, "Lack of appropriate collection, storage, and treatment system for septage waste and municipal solid waste (B1)" presents the highest value of (R+C), suggesting its high level of prominence, whereas "Lack of public willingness to use bio-fertilizer from co-composting of municipal solid waste and septage waste (B8)" shows the lowest level of prominence.

Table 2: Direct relation matrix (Z)

Label	B1	B2	B3	B4	B5	B6	B7	B8
B1	0.000	2.615	1.615	1.846	2.308	1.769	2.462	1.846
B2	2.077	0.000	1.846	1.231	1.385	1.846	2.154	2.923
B3	2.462	2.154	0.000	1.462	1.615	1.692	1.538	1.846
B4	2.692	2.154	1.538	0.000	2.538	2.308	2.538	1.923
B5	3.231	2.462	2.154	2.538	0.000	2.231	2.538	1.846
B6	2.385	2.692	2.154	2.077	1.769	0.000	1.615	2.231
B7	2.538	2.692	1.615	1.615	1.769	1.692	0.000	1.692
B8	2.231	1.692	2.077	1.308	1.154	1.000	1.385	0.000

Table 3: Normalized Direct relation matrix (X)

Label	B1	B2	B3	B4	B5	B6	B7	B8
B1	0.000	0.148	0.092	0.105	0.131	0.100	0.140	0.105
B2	0.118	0.000	0.105	0.070	0.079	0.105	0.122	0.166
B3	0.140	0.122	0.000	0.083	0.092	0.096	0.087	0.105
B4	0.153	0.122	0.087	0.000	0.144	0.131	0.144	0.109
B5	0.183	0.140	0.122	0.144	0.000	0.127	0.144	0.105
B6	0.135	0.153	0.122	0.118	0.100	0.000	0.092	0.127
B7	0.144	0.153	0.092	0.092	0.100	0.096	0.000	0.096
B8	0.127	0.096	0.118	0.074	0.066	0.057	0.079	0.000

Table 4: Total relation matrix (T)

Label	B1	B2	B3	B4	B5	B6	B7	B8
B1	0.502	0.607	0.468	0.452	0.487	0.462	0.543	0.518
B2	0.563	0.435	0.446	0.391	0.411	0.430	0.490	0.531
B3	0.567	0.532	0.340	0.393	0.414	0.415	0.453	0.470
B4	0.677	0.626	0.496	0.388	0.530	0.518	0.582	0.555
B5	0.739	0.677	0.553	0.541	0.433	0.543	0.614	0.585
B6	0.630	0.619	0.501	0.468	0.470	0.377	0.512	0.545
B7	0.598	0.584	0.446	0.420	0.442	0.437	0.396	0.488
B8	0.492	0.449	0.397	0.339	0.345	0.335	0.391	0.321

Table 5 summarizes the barriers' prominence (*R* + *C*) and net relation (*R* - *C*) index. The net relation index (*R*-*C*) values indicate that "Lack of regulatory enforcement and implementation to control the illegal disposal of municipal solid waste and septage waste (B5)" is the major cause of other barriers, followed by "Lack of cooperation and coordination between the responsible authorities for municipal solid waste and septage waste management (B4)" and " Lack of financial support for theco-management of septage waste and municipal solid waste (B6)". On the other hand, the effect barriers are "Lack of appropriate collection, storage, and treatment system for septage waste and municipal solid waste (B1)", "Lack of composting facilities for co-management of septage waste and municipal solid waste (B2)", "Lack of human resources in the field of waste management (B3)", "Lack of public willingness to segregate the municipal mixed solid waste (B7)" and "Lack of public willingness to use bio-fertilizer from co-composting of municipal solid waste and septage waste (B8)" (see Table 5). The prominence (*R*+*C*) values indicate that "Lack of appropriate collection, storage, and treatment system for septage waste and municipal waste(B1) is the most high level of prominence of other barriers, followed by "Lack of composting facilities for co-management of septage waste and municipal solid waste (B2)", "Lack of regulatory enforcement and implementation to control the illegal disposal of municipal solid waste and septage waste (B5)", "Lack of public willingness to segregate the municipal mixed solid waste (B7)", B4, B6, B3, and B8 (see Table 5).

Table 5: Summary of barrier's prominence (R + C) and net relation (R - C) index

Barrier	R	C	R + C	R - C	Group
B1	4.038	4.767	8.806	-0.729	Effect
B2	3.697	4.528	8.224	-0.831	Effect
B3	3.584	3.646	7.230	-0.062	Effect
B4	4.372	3.391	7.763	0.981	Cause
B5	4.683	3.531	8.214	1.152	Cause
B6	4.121	3.517	7.638	0.604	Cause
B7	3.811	3.982	7.792	-0.171	Effect
B8	3.070	4.013	7.083	-0.944	Effect

a) Chord diagram of barriers b) Problematic causal map

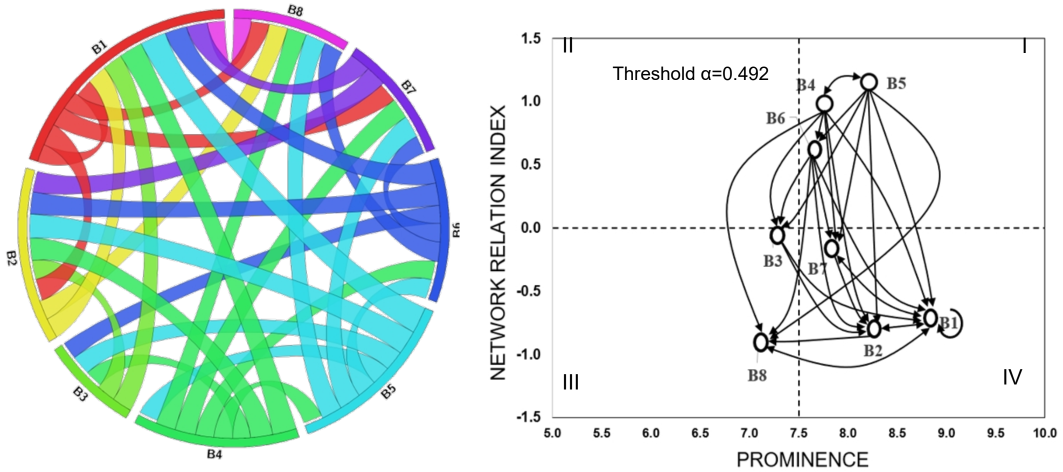

Figure 1: Interrelationship of the barriers to co-management of urban bio-wastes in Phnom Penh

Figure 1(a) shows the chord graph of the inner dependency of barriers where a threshold value of α=0.492 is applied to filter out the minor influences of the causal relationship among barriers. The connection of the chord between barriers represents the influential relationship among barriers, while the color of the chord indicates the influence of one barrier on another. For instance, B1 represented by the red color, is not connected to B5 by the red chord, suggesting that B1 has no influence on B5 while the light-blue chord connects from B5 to B1, indicating that B5 represented by the light-blue color, influences B1. Similarly, as it is depicted by the dominant chord colors, B4, B5, and B6 have a large number of chords connected to all other barriers, signifying their effects on another barrier. In fact, the interaction between barriers could be observed by the number of chords connected to each barrier, and the dominant color signifies the influential barriers. A problematic causal map of the barriers is plotted with the x-axis as prominence and the y-axis as network relation index (See Figure 1(b)). This map is divided into four quadrants: quadrants I and II as the cause and quadrants III and IV as the effect. It is important to note that the challenges of co-management of urban bio-waste in Phnom Penh could only be solved systematically through the identification of the prominent causes which require attention for actionable policy recommendations. B5 located at the highest point in the problematic causal map, followed by B4 and B6 in quadrant I, is the key causal barrier to other barriers located in quadrants III and IV, i.e., B1, B2, B3, B7, and B8. This finding emphasizes the necessity to reinforce regulation and control the illegal disposal of municipal solid waste and septage waste as mandatory law and regulation directly impact waste management behavior (Lee and Paik, 2011). The accountability and responsiveness in improving waste management behavior could begin with the wide use of a digital platform, i.e., Waste Tracker App, based on which all stakeholders could view and report concerns on the illegal disposal of municipal solid waste and septage waste (USAID, 2020). Moreover, B4 is the second causal barrier to be addressed to ensure the well co-management of urban bio-waste, suggesting that the cooperation and coordination between the responsible authorities for municipal solid waste and septage waste management need to be explicitly secured with the strategic communication (Badiru, 2008) while the allocation of financial support (B6) from the national budget is indispensable. At the far right of the problematic causal map in quadrant IV, B1 with the self-loop has the highest prominence index suggesting this barrier is highly linked to other barriers. This critical and important highly-linked barrier (B1) has been taken into significant consideration by the Royal Government of Cambodia, e.g., three new garbage collection companies were contracted to collect, clean, and transport waste in Phnom Penh from July 2021 (Khmer Time, 2021) whereas the wastewater treatment facility has been constructed (Sokchan, 2022). Despite all challenges to overcoming each barrier to co-managing the urban bio-waste in Phnom Penh, the capital city of Cambodia, the present finding provides insight and justification for the strategic action plan implemented by the relevant stakeholders. Moreover, based on the experts' responses during the survey, the lack of public willingness to use bio-fertilizer from co-composting of municipal solid waste and septage waste (B8) is the least influential barrier compared to all barriers indicating that bio-fertilizer is likely and socially accepted in Cambodia.

4. Conclusions

The proposed method is used to understand the barriers to implementing such co-management of organic waste and human excreta in Phnom Penh, the capital city of Cambodia, by using the DEMATEL method. A problematic causal map of the barriers can be utilized to visualize how barriers are interconnected and propose the intervention in co-managing the urban bio-wastes. Thus, this study emphasizes the key barriers that need prompt attention to improve the co-managing of such wastes, especially the lack of regulatory enforcement and implementation to control the illegal disposal of municipal solid waste and septage waste (B5). Proper intervention to address such barriers is needed to resolve such problems. Moreover, the Royal Government of Cambodia should consider establishing the composting facilities for co-management of septage waste and municipal solid waste while improving waste collection, storage, and treatment could be done stepwise. By understanding the most correlated and influential barriers, insight from the present study could be materialized into the actionable policy recommendations with the vision to achieve SDG goals and explore the benefit of a circular economy.

Acknowledgments

The authors acknowledge the support of the Department of Science and Technology-Science Education Institute (DOST-SEI), and all experts group from Governments, Development Partners, Academics, and Private Companies for their cooperation and support.

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