CHEMICAL ENGINEERING TRANSACTIONS

VOL. 76, 2019

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar S. Varbanov, Timothy G. Walmsley, Jiří J. Klemeš, Panos Seferlis

ISBN 978-88-95608-73-0; **ISSN** 2283-9216

DOI: 10.3303/CET1976021

Determining the Causality between Drivers of Circular Economy using the DEMATEL Framework

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A trend arises among industrial and government sectors to transition from the conventional economic system to the new Circular Economy. Its benefit of material security, resource efficiency, and economic growth has attracted government institutions and business sectors to adopt the new trend. However, its challenge falls on the real complexities of economic systems. Adoption of the Circular Economy requires careful consideration of possible challenges. Previous works have aimed to identify the drivers of Circular Economy through surveys based on the frequency of data. The results provided useful information for the decision making of the transition. However, it is also limiting as it does not address a plausible chain-like effect of the drivers which can aid stakeholders determine which course of action is necessary for an efficient transition. Hence, this study is focused in determining these causal drivers by using the DEMATEL approach. DEMATEL is a methodology that identifies the cause and effect relationship between drivers, of which, it can then determine the top causal driver. The study uses a case study in the Philippines to illustrate the capability of the methodology of determining the causality between drivers of Circular Economy. The results of the case study were able to identify 'economic attractiveness', with a net cause/effect value of 1.22, and 'consumer demand', with a net cause/effect value of 0.87, as the main causal driver while 'company culture', with a net cause/effect value of -1.22, as the main effect. The result implies that the improvement in the circular business models and increase in customer awareness are the top priority for the transition. The application of this work is intended to provide researchers an alternative approach in identifying the critical causal drivers of Circular Economy.

1. Introduction

Raw material extraction has increased for the past few decades. From 1970, the global extraction rate was at $26.7 x 10^9$ t/y, until 2010, it was at $75.6 x 10^9$ t/y (IRP, 2017). At this rate, economic development will become unsustainable and lead to scarcity of future resources. The current economic system of 'take-make-dispose' approach adheres to a linear flow of resource utilization demanding for more virgin materials (Ellen MacArthur Foundation, 2013). Efficiently utilizing the raw materials of the economic system can help in the decrease of its extraction rate. This practice is promoted in the Circular Economy (CE). It is an economic system that reutilizes a product's end-of-life phase for the benefit of the economy, the environment, and society (Kircherr et al., 2017). Government institutions such as China (Jiang, 2018), Malaysia (Hishammuddin et al., 2018) and the European Union (Houston et al., 2018) have shown interest in transitioning to the new economic system. Its implementation can lead to reduced emissions and material losses, and promote new business models (Reichel et al., 2016).

Transition to the CE system is difficult and complicated. The process must consider economic, social, environmental, and political factors. Stakeholders will need to be knowledgeable on the drivers of CE for impactful decision making. Recent works have identified the factors through interviews, survey data, literature review, and focus group discussion. Ritzén and Sandström (2017) have interviewed companies on the perspective on the barriers of CE. Houston et al. (2018) have conducted a focus group discussion on the barriers

Paper Received: 16/03/2019; Revised: 06/05/2019; Accepted: 06/05/2019
Please cite this article as: Gue I.H.V., Ubando A.T., Promentilla M.A.B., Tan R.R., 2019, Determining the Causality between Drivers of Circular Economy using the DEMATEL Framework, Chemical Engineering Transactions, 76, 121-126 DOI:10.3303/CET1976021

and enablers of CE. Kircherr et al. (2018) surveyed 208 respondents of the European Union on the barriers of CE. Rizos et al. (2016) have utilized survey data in identifying the barriers and enablers of CE for small and medium-sized enterprises. Araujo Galvão et al. (2018) conducted a literature review to identify the barriers of CE. Govindan and Hasaganic (2018) did a literature review on the drivers and barriers of CE in the supply chain. Previous studies have identified the main drivers and barriers based on the frequency of the data. It reflects the common perception of the stakeholders. However, it is limited in realizing the chain-like relationship of the drivers and barriers. The chain-like relationship is best illustrated in the study of Kircherr et al. (2018) which conducted interview with stakeholders. The result of the interview has led to the realization of existing causal links in the barriers of CE. Figure 1 shows a sample chain reaction of barriers as described in their work. The arrows in the figure portray the causal relationship of the barriers while the numerical values portray the frequency of the mentioned barrier. It is evident from the figure that the lack of consumer awareness is the most frequently mentioned barrier. Kircherr et al. (2018) noted that aside from the results, there could exist a causal reaction. The causal reaction can follow with the lack of available data restricting the funding for circular business models. Limited business models can lead to neglect in the need to modify the existing laws and regulations. Eventually, the restricting laws and regulations will lessen the promotion of CE for customer awareness. Even though the result identified consumer awareness as the main barrier, in reality, the lack of data is the real causal barrier. Decisions targeting the lack of data may be more effective as compared to targeting the lack of consumer awareness. Establishing the interrelationship between the barriers or drivers can help determine the critical factor to consider. This study determines this interrelationship with the use of DEMATEL. The DEMATEL framework establishes the interrelationship between factors based on a Likert scale data of their causal relationships. The Likert scale data is advantageous as it can determine the level of influence between the factors. Mangla et al. (2018) did similar work in determining the interrelationship on the barriers of CE with the use of a hybrid ISM-MICMAC framework. This work differs with the work of Mangla et al. (2018) as DEMATEL can utilize a Likert scale for quantifying the level of influence whereas ISM cannot. This work presents a Philippine case study to demonstrate the capability of DEMATEL in identifying the main causal driver of CE.

This study is organized as follows. The next section discusses the theoretical framework of DEMATEL and its procedures. Section 3 discusses the case study used for testing the proposed methodology. Section 4 discusses the results obtained from the survey carried out. Section 5 discusses the conclusion and future work.

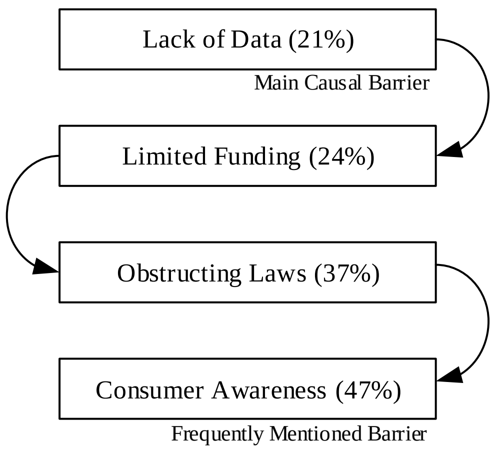

Figure 1: Sample Chain Reaction of Barriers from Kircherr et al. (2018)

2. Theoretical framework

The DEMATEL framework is intended to determine the causal relationship between the drivers. Batelle Memorial Institute was the first that proposed this framework (Fontela and Gabus, 1972). Research works utilized this framework for various applications such as for identifying barriers of an eco-industrial park (Promentilla et al., 2016) and factors for innovation in a CE system (Zheng et al., 2011). DEMATEL is capable of representing the causal relationship of the drivers, their prominence, and their inter-dependency to each other. The methodology utilizes pairwise comparisons on the causal influence between drivers i and j, denoted as a_{ijk} where k is the response of the k^{th} respondent. The arithmetic mean of the responses, denoted as $\bar{a}_{ij}$, are treated as the consensus of the responses. Matrix A then groups the elements of the arithmetic mean represented in Eq(1). Rows of matrix A signify the influence of i to j while the columns represent the dependence of j from i. Normalization of matrix A is then carried out using Eq(2). This equation normalizes the elements to the maximum causal influence of a factor. Matrix B groups the normalized elements represented in Eq(3).

$$\overline{\mathrm{A}} = \begin{bmatrix} 0 & \cdots & \bar{a}_{1j} \\ \vdots & \ddots & \vdots \\ \bar{a}_{i1} & \cdots & 0 \end{bmatrix} \quad (1)$$

$$b_{ij} = \frac{\bar{a}_{ij}}{\max_{1 \le i \le n} \sum_{j=1}^{n} \bar{a}_{ij}} \quad (2)$$

$$\mathrm{B} = \begin{bmatrix} 0 & \cdots & b_{1j} \\ \vdots & \ddots & \vdots \\ b_{i1} & \cdots & 0 \end{bmatrix} \quad (3)$$

Normalized matrix B only represents the direct causality of the drivers. It can represent causal links such as $b_{11} \rightarrow b_{22}$ but cannot represent links such as $b_{11} \rightarrow b_{33} \rightarrow b_{22}$. DEMATEL considers these indirect links by using the infinite series equation shown in Eq(4). The resulting matrix is denoted as the Total Relation Matrix C.

$$\mathrm{C} = \mathrm{B}(\mathrm{I} - \mathrm{B})^{-1} \quad (4)$$

Summing up the elements of each row in matrix C, as shown in Eq(5), yields the Cause Vector D, represented by Eq(6). Similarly, adding the elements of each column in matrix C, as shown in Eq(7), yields the Effect Vector E, represented by Eq(8). The difference between the two vectors, D and E, indicates the net causality of the drivers while the sum of the two vectors indicates the prominence of the drivers. A positive value in the net causality, D-E, identifies the driver as causal while a negative value identifies it as affected. The prominence, D+E, is interpreted as the level of significance of the driver.

$$d_i = \sum_{j=1}^{n} c_{ij} \quad (5)$$

$$\mathrm{D} = \begin{bmatrix} d_1 \\ \vdots \\ d_i \end{bmatrix} \quad (6)$$

$$e_i = \sum_{i=1}^{n} c_{ij} \quad (7)$$

$$\mathrm{E} = \begin{bmatrix} e_1 \\ \vdots \\ e_i \end{bmatrix} \quad (8)$$

Eliminating specific elements of the Total Relation Matrix C yields the Inner-Dependency Matrix which signifies the relevant causal links between the drivers. A threshold value α is calculated using Eq(9), where m is the total number of elements in matrix C. Elements with values lower than the threshold value are omitted from matrix C yielding the Inner-Dependency Matrix. The Prominence-Causal Relationship Diagram will then visually represent the Inner-Dependency Matrix with arrows indicating the flow of influence between the drivers. This flow of influence indicates the expected chain-like reaction of the drivers.

$$\alpha = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} c_{ij}}{m^2} \quad (9)$$

3. Case study

This work presents a case study to demonstrate the capability of the DEMATEL. It considers the case of determining the causal drivers of CE in the Philippines. The country has already initiated actions for transitioning to CE with the Department of Science and Technology (DOST) hosting forums in 2018 on the benefits of CE to the country. Industries in the textile are among the initial sectors that have shown willingness to participate in the proposed economic system (Reyes, 2017). Other industries have shown interest in CE by recycling sachet for manufacturing bricks (Reyes, 2017), and by targeting to produce recyclable plastic packaging (Unilever Philippines, 2019). It is essential to identify the primary driver of CE in the Philippines to help stakeholders proliferate the practice to other business sectors. This case study obtained responses from 15 representatives across different business sectors in the Philippines and is only intended for demonstration of DEMATEL to

identify the main drivers of CE. Determining the general inclination of the country's business sector would require a larger sample size.
The study utilized the Likert scale as the rating for the pairwise comparison between the drivers as shown in Table 1. The survey given to the respondents constitutes comparisons between 6 drivers of CE as enumerated in Table 2. The top enumerated factors from other literature formed the basis of these considered drivers. The enumerated drivers generated a total of 30 comparisons or questions for the respondents.

Table 1: Five Point Scale Survey for the Case Study

Scale	Rating
0	No Influence
1	Low Influence
2	Medium Influence
3	High Influence
4	Very High Influence

Table 2: Identified Circular Economy Drivers

Legend	Drivers	Description	Reference
D1	Support from the government	Legislation of the government directly promoting circular economy	Houston et al. (2018) Rizos et al. (2016)
D2	Company culture	The willingness of companies to adopt 'circular' practices	Houston et al. (2018) Kircherr et al. (2018) Rizos et al. (2016)
D3	Consumer demand	Demand from the consumer for 'circular' products	Houston et al. (2018) Kircherr et al. (2018) Rizos et al. (2016)
D4	Social recognition	Awards or recognition to 'circular' business models	Houston et al. (2018) Rizos et al. (2016)
D5	Economic attractiveness	Financial profitability of 'circular' business models	Houston et al. (2018) Rizos et al. (2016)
D6	Information to practitioners	Industry's awareness of the concept	Rizos et al. (2016)

4. Results

Table 3 shows the arithmetic mean of the responses obtained. Normalization was carried out using Eq(2) yielding the normalized matrix B. The Total Relation Matrix C calculated from Eq(4) are tabulated in Table 4. The calculated threshold value α is 1.26. Elements with a value less than α were removed from matrix C to form the Inner-Dependency Matrix also represented in Table 4 as the values enclosed in parenthesis. The flow of the Inner-Dependency Matrix is illustrated by the Prominence-Causal Relationship Diagram shown in Figure 2 where the arrow indicates the direction of influence of one driver to the other. The value of each driver on their net cause/effect vector, D-E, and prominence vector, D+E, are also visualized in Figure 2.

Table 3: Average Survey Data from Stakeholders

A	D1	D2	D3	D4	D5	D6
D1	0.00	3.20	2.33	2.07	2.73	2.40
D2	2.20	0.00	2.40	2.93	2.33	2.80
D3	2.93	3.13	0.00	3.00	3.40	3.13
D4	2.87	2.93	2.87	0.00	2.27	2.67
D5	3.33	3.13	3.33	2.73	0.00	2.93
D6	2.53	2.87	2.87	2.40	2.13	0.00

Table 4: Total Relation Matrix of the Case Study

C	D1	D2	D3	D5	D6	D7
D1	(1.06)	1.33	(1.19)	(1.14)	(1.15)	(1.20)
D2	(1.18)	(1.15)	(1.19)	(1.17)	(1.12)	(1.22)
D3	1.42	1.55	(1.26)	1.38	1.37	1.44
D5	1.28	1.38	1.27	(1.08)	(1.18)	1.28
D6	1.43	1.54	1.43	1.35	(1.18)	1.42
D7	(1.21)	1.32	(1.22)	(1.16)	(1.13)	(1.08)

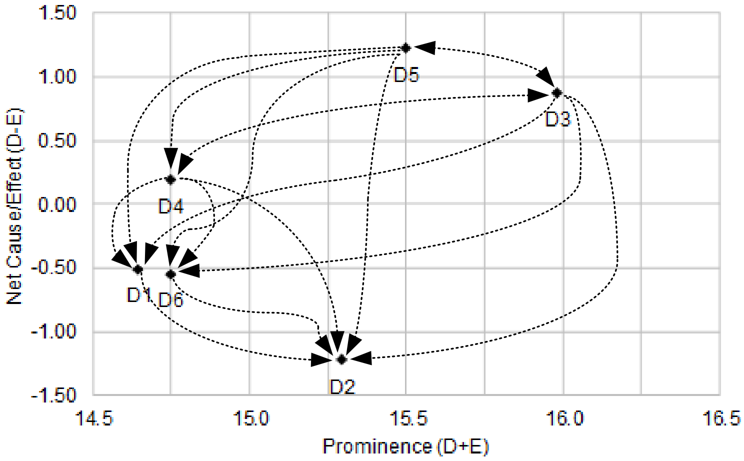

Figure 2: Prominence-Causal Relationship Diagram of the Case Study

Results shown in Figure 2 identifies drivers D5 (economic attractiveness), with a D-E value of 1.22, and D3 (consumer demand), with a D-E value of 0.87, as the cause drivers while driver D2 (company culture), with a D-E value of -1.22, is the most affected one with a negative D-E. Driver D4 (social recognition) is another causal driver but has a relatively low D-E value of 0.19 indicating weak influence to the other drivers. Drivers D1 (support from the government), and D6 (information to practitioners) are the other affected drivers but have a relatively higher D-E value of -0.51 and -0.54 indicating that the other drivers weakly influence them. The identified causal and affected drivers, D5, D3, and D2, also have the highest prominence value, D+E, indicating their level of significance.

Causal links visually represented by Figure 2 also show that drivers D5 and D3 have the highest number of influences as both drivers have a strong influence over drivers D1, D2, D4, and D6 while driver D2 is the most affected one as all drivers have a strong influence over it. A double-headed arrow in Figure 2 indicates the existence of a bi-directional relationship wherein both drivers can supplement each other at the same time. The relationship is present between drivers D5 and D3, and between drivers D4 and D3.

The results of the case study provide an insight into what are the essential drivers to consider by the stakeholders. Decisions can then focus on driver D5 (economic attractiveness) by developing new CE business models with a high financial return or on driver D3 (consumer demand) by marketing the benefits of CE to the general public. The actions can then lead to establishing social recognition for CE practices, driver D4 (social recognition), increasing the pressure to policymakers, driver D1 (support from the government), and providing efficient information dissemination to the practitioners, driver D6 (information to practitioners). All the drivers would then lead to a change in perspective of the business sectors, driver D2 (company culture).

5. Conclusion

This study utilized DEMATEL in determining the main causal drivers for the transition to the Circular Economy (CE). It verified the proposed framework to a case study on the business sectors in the Philippines. The methodology identified the main causal driver of the case study and also identified the main affected driver. Results revealed that economic attractiveness of the business model and consumer demand of 'circular' products as the causal drivers and the company culture as the affected driver. Decisions can be made to consider actions directly addressing business models or consumer awareness. The results also provide an insight on the amount influence each driver has. Determining the general inclination of the country's business

sector will require a larger sample size than the one used in this study. This study only demonstrated the capability of DEMATEL in identifying the critical drivers for the transition to CE.
Perspectives of the different respondents are present in the survey data which may lead to discrepancies of the survey results. Future works can investigate on treating the inconsistency of DEMATEL. Methodologies such as corrected item-correlation approach or split-half methods as suggested by Shieh and Wu (2016) can be used to enhance the robustness of the survey result.

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