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ORIGINAL RESEARCH PAPER

Modeling barriers of solid waste to energy practices: An Indian perspective

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ABSTRACT: India is rapidly urbanizing and the class I cities contribute more than 72 percent of the total solid waste generated in urban areas. However managing solid waste scientifically has become one of the biggest challenges in front of state and local authorities. Limited space for dumping and skilled manpower is a constraint for managing the solid wastes. Illegal dumping outside cities and unscientific processing often leads to foul odor generation, leachate contaminating the water streams and spreading of germs detrimental to public health and society. Globally environmental scientists are looking for innovative and sustainable methods for recovering the useful components from waste consisting of value and can be reused. Presently several waste to energy projects have gained popularity across the world. Unfortunately none of these practices have gained popularity in India and further motivated in pursuing the present study. The objective of the study is twofold. First authors assessed the current status of solid waste management practices in India. Secondly the leading barriers are identified and interpretive structural modeling technique is performed to identify the contextual interrelationships between leading barriers influencing the solid waste to energy programs in the country. The dependence and driving power of the barriers are further analyzed. Finally the conclusions are drawn which may assist policy makers in designing sustainable waste management programs.

KEYWORDS: *Solid waste management (SWM); Waste to Energy technology; Barriers; interpretive structural modeling (ISM); Matrice d'impacts croises multiplication appliqué à un classement (MICMAC)*

INTRODUCTION

Sustainable waste management framework is the pressing call of the day in a developing country like India. The population of India has increased by more than 181 million during the decade 2001-2011 (Census, 2011). Urban India generates 68.8 million tons of municipal solid waste per year (SWM India, 2011). The importance of the subject is reflected in the themes of conferences and growing number of publications. However several barriers are hindering the progress of solid waste to energy projects in India.

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The main objectives of this study are:
1. To assess the current status of solid waste management practices in India.
2. To identify the barriers influencing solid waste to energy programs in India

3. To determine the interactions among the identified barriers; and
4. To understand the managerial implications of this study.

Waste to energy status

The present review has been attempted to assess the current status of waste to energy programs in India and abroad. Review has been conducted from reputed peer reviewed journals, books and published secondary sources. Several researchers have reported the status of conversion of waste to energy (Bag *et al.,* 2015; Kalyani and Pandey, 2014; Kothari *et al.,* 2010; Swati *et al.,* 2008; Joseph, 2007; Cheng et al., 2007; Esakku *et al.,* 2006; Joseph, 2006; Nagendran *et al.,* 2006; Jin *et al.,* 2006; Finnveden *et al.,* 2005; Murphy and McKeogh, 2004; Kathirvale *et al.,* 2004; Girija and Kurian, 2004; Kumar, 2000; Ruth, 1998; Lorber *et al.,* 1998; Miranda and Hale, 1997; Huang *et al.,* 1992). Waste to energy practices involves any process that produces energy efficiently in the form of power, heat or fuel from municipal solid waste, commercial waste, domestic sewage, and gaseous wastes. Thus, far municipal solid waste has been popularly used for converting into energy. The generated power can be distributed through state and national grid systems to meet the growing demand of developing countries.

Table 1 presents published research papers per country on waste to energy conversion which shows the growing interest and importance of the topic.

There are several 'waste to energy' technology choices available today and they have been presented in Table 2. Each technology has its own limitations and therefore its selection requires careful consideration of several critical parameters.

In India the Ministry of New and Renewable Energy has been promoting the use of technologies for energy recovery from municipal, industrial and commercial wastes, for meeting certain niche energy demands of urban, industrial and commercial sectors in the country. However, most of the 'W to E' plants are non-functional and require immediate attention. Table 3 shows the status of "W to E" plants in India.

The earlier review provides an overview of the enormous challenges in converting solid waste to energy. Presently 68.8 million tons of MSW is generated annually in urban areas (Parvathamma, 2014). This poses a serious threat to the municipal authorities due to lack of landfill space. There are 279 composting, 138 vermi composting, 15 bio-methanation, 29 palletization and 8 waste to energy municipal solid waste facilities in India (Planning commission report, 2014). Unfortunately only few of these facilities are presently operational as presented

Table 1: Publications on solid waste to energy in different countries

Author (s)	India	Bangladesh	China	Hong Kong	Taiwan	Malaysia	Sweden	USA	Tanzania	Portugal	Nigeria	Turkey
Bag *et al.,* (2015)	X											
Kalyani; Pandey 2014)	X											
Unnikrishnan; Singh (2010)	X											
Cheng; Hu (2010)			X									
Psomopoulos *et al.,* (2009)	X							X				
Narayana (2009)	X											
Sharholy *et al.,* (2008)	X											
Islam *et al.,* (2008)		X										
Talyan *et al.,* (2007)	X											
Cheng *et al.,* (2007)			X									
Kofoworola (2007)											X	
Magrinho *et al.,* (2006)										X		
Tsai; Chou, (2006)					X							
Finnveden *et al.,* (2005)							X					
Ravindranath *et al.,* (2005)	X											
Eriksson *et al.,* (2005)							X					
Kathirvale *et al.,* (2004)						X						
Mbuligwe; Kassenga (2004)									X			
Kathiravale *et al.,* (2003)						X						
Metin *et al.,* (2003)												X
Akinbami *et al.,* (2001)											X	
Ruth (1998)								X				
Lorber *et al.,* (1998)								X				
Chung; Poon (1996)				X								
Alter; Dunn (1980)								X				

Table 2: Waste to energy technology options

Thermo-chemical conversion	Incineration Co-combustion Residual derived fuel plant Thermal gasification
Bio-chemical conversion	Bio-ethanol production Dark fermentation and Photo Fermentation producing bio-hydrogen Biogas production from anaerobic digestion Biogas production from landfills Microbial fuel cell
Chemical conversion	Esterification

Source: Authors self-compilation

Table 3: Status of waste to energy plants in India

State	No. of waste to energy processing facilities	Site	Plant capacity (MTD)	Electricity generated (MW)	Status
Andhra Pradesh	2	Shriram energy systems limited plant in Vijayawada	N.A	6	Non functional
		Hyderabad	N.A	6	Under installation
Delhi	3	Timarpur - Okhla waste to energy plant	1950	16	Operational
		Ghazipur waste to energy plant	1300	12	Under installation
		Narela waste to energy plant	3000	24	Under installation
Kerala	1	Venkatamangalam village	300	3	Trial run
Maharashtra	2	Solapur		3	Functional
		Pune, Hadapsar	700	10	Non functional

Source: Authors self- compilation

in Table 2. As per the planning commission of India 2014 report there is a high potential of converting solid waste to energy which has the capacity of generating 439 municipal waste of power from 32,890 tons per day of combustible waste. The processing and energy generation will not only generate revenue and usable component but also improve the public health system. It is strongly felt to identify the leading barriers currently hindering management of solid waste and understand their interrelationships to find new ways of managing solid waste management programs.

MATERIALS AND METHODS

ISM based model

The research was conducted using the interpretive structural modeling (ISM) methodology, which is used to identify the interrelations of the barriers. Interpretive structural modeling is the most popular modeling approach. ISM uses experts to judge the factors/ variables under study, and the relations among them are interpreted. ISM generates deep knowledge of the subject and is greatly helpful for practitioners. ISM has been used in the past by several researchers (Bag and Anand, 2015; Bag and Anand, 2014; Bag *et al.,* 2014; Attri and Sharma, 2013; Sushil, 2012; Sushil, 2009; Sushil, 2005a; Sushil, 2005b; Warfield, 1999; Warfield, 1994; Warfield, 1974) for multiple benefits such as systematic process, efficient process, creates a structural model of the initial problem situation and serves as a learning tool (Attri and Sharma, 2013).

Findings of Barriers from earlier studies

Eighteen barriers were found to be influencing waste to energy practices. A problem-solving group was formed comprising five experts from urban local bodies (ULBs). The group was asked to analyze the listed barriers, take out the repeated ones and rearrange the list including the ones thought to be valid in relation with Indian context (Table 4). The first tour resulted with reducing each of the barriers to 16. Through the second tour 13 and the third tour total 12 barriers were determined. The underlying reasons for unsuccessful waste to energy practices can be attributed due to the following barriers:

Poor waste management planning

Lack of short, medium and long term waste management planning, poor assessment of technical,

Table 4: Twelve barriers identified from earlier studies and validated through experts' opinion

Sl No	Barriers	References
1	Poor waste management planning	Ojha (2011); Planning commission report for India (2014)
2	Wrong selection of waste to energy technology	Ojha (2011); Planning commission report for India (2014)
3	Wrong selection of Location	Ojha (2011); Planning commission report for India (2014)
4	Poor contract management	Forsyth (2006); Planning commission report for India (2014)
5	No benchmarking to assess efficiency of services	Ojha (2011); Planning commission report for India (2014)
6	Incomplete legislation and insufficient enforcement	Ojha (2011); Planning commission report for India (2014)
7	Financial strain on urban local bodies	Ojha (2011); Planning commission report for India (2014)
8	Poor budget monitoring	Ojha (2011); Planning commission report for India (2014)
9	Insufficient public education	Ojha (2011); Planning commission report for India (2014)
10	Limited community participation	Forsyth (2006); Ojha (2011); Planning commission report for India (2014)
11	Inadequately trained human resources	Ojha (2011); Planning commission report for India (2014)
12	Labour conflict	Ojha (2011); Planning commission report for India (2014)

environmental and economic aspects of waste collection, recycling, treatment and disposal before commencing of waste to energy projects leads to poor control at a later stage.

Wrong selection of Waste to Energy technology

Selection of technology depends upon the nature of waste and essentially the quantity of waste generated on a daily basis for input in the process cycle and convert into useful components. In most of the non functional 'W to E' projects it has been found that wrong process adoption without proper technical evaluation is the root cause of project failures.

Wrong selection of Location

Location of the 'W to E' project site is very important from project success perspective. Wrong selection of location is the not only the cause of project failures of most of the 'W to E' plants but also most of the composting plants in India are being shut down due to the same reason. The poor quality of local infrastructure limits truck access to the project site and impacts the economic aspects. Wrong selection of location also leads to social and environmental problems such as spreading of germs and emission of foul odor from the waste which creates local turmoil, agitation among local people and creates situation like gherao. The local pressures ultimately forces ULB to stop the 'W to E' plant operation. Ideally the site should be selected outside the city away from public and maintain a buffer zone to avoid such incidents.

Poor contract management

Due to lack of in-house capacity of ULBs' and scarcity of resources, all the 'W to E' projects operate under public private partnership (PPP) model. The service contact signed between the ULB and private firm should be complete with all terms and conditions. The reason of failure of majority of the 'W to E' projects is due to conflicts which arise between municipal authority and private company due to vague terms in contract. The lack of clarity resulted in dispute which leads to closure of plant.

No benchmarking to assess efficiency of services

Lack of tracking and performance measurement is the cause of failure of several 'W to E' projects. Benchmarking is an essential tool to save operational costs and has been ignored in these 'W to E' projects.

Incomplete legislation and insufficient enforcement

Lack of strong legislation and insufficient powers to prevent pollution is another reason for unsuccessful 'W to E' projects. Weak enforcement is the cause of lack of attention in waste management practices by municipal authorities.

Financial strain on urban local bodies

Central and state bodies must reduce the financial strain on ULBs which has been the major barrier of 'W to E' projects.

Poor budget monitoring

Poor monitoring of budgets by ULBs often lead to overspending and caused financial crunch.

Insufficient public education

Less focus has been given on public education by local ULB which resulted in low awareness of 'W to E' technologies, the social and environmental benefits which resulted in public agitation in most of the projects.

Limited community participation

While selecting the ‘W to E’ technology it is essential that members from the local community participate in the discussion and understand the entire operations. The comments of the community members are essential before an ULB go ahead for final signing of contract and further investment in project. This has never been practiced so far and main reason of conflicts at the later project stage.

Inadequately trained human resources

Lack of in-house resources and competency is a major barrier in ‘W to E’ projects. Lack of knowledge in handling and running equipment and machineries is the cause of project failures.

Labour conflict

Lack of knowledge in handling and running machineries, lack of health and safety instructions often lead to major accidents. Moreover low wages and lack of proper HR management is the cause of conflicts among labour groups with ULB and main cause of stoppage of plant operations.

RESULTS AND DISCUSSION

In this study the contextual relationships between pair of barriers are analyzed. For the purpose of understanding and capturing the data, a questionnaire was prepared and sent to seven SWM inspectors working with various ‘W to E’ projects. The data is converted into SSIM matrix which is further converted into reachibility matrix. Further the level partitions are done and the ISM model is developed.

Structural self interaction matrix (SSIM)

For developing SSIM in Table 5, the following symbols have been used to denote the direction of relationships between variables (i and j):

V: i leads to j but j does not lead to i
A: i does not lead to j but j leads to i
X: i leads to j and j leads to i
O: i and j are unrelated to each other

Reachibility matrix

The SSIM has been converted into a binary matrix i.e., the reachibility matrix (Table 6) by substituting V, A, X and O by 1 and 0. The substitutions of ‘1’ and ‘0’ are done as below:

I. If the (i, j) entry in the SSIM is V, then the (i,j) entry in the reachibility matrix becomes ‘1’ and (j,i) entry becomes ‘0’
II. If the (i, j) entry in the SSIM is A, then the (i,j) entry in the reachibility matrix becomes ‘0’ and (j,i) entry becomes ‘1’
III. If the (i, j) entry in the SSIM is X, then the (i,j) entry in the reachibility matrix becomes ‘1’ and (j,i) entry also becomes ‘1’
IV. If the (i, j) entry in the SSIM is O, then the (i,j) entry in the reachibility matrix becomes ‘0’ and (j,i) entry also becomes ‘0’

Table 5: Structural self interaction matrix

	12	11	10	9	8	7	6	5	4	3	2	1
1	V	O	O	V	V	V	A	V	V	V	V	
2	V	O	A	O	O	O	O	A	O	O		
3	V	O	O	O	O	V	V	A	A			
4	V	A	O	O	O	O	A	A				
5	V	A	O	O	O	O	A					
6	O	O	O	O	O	O						
7	V	V	O	O	A							
8	V	V	O	V								
9	V	A	V									
10	O	O										
11	V											
12												

Table 6: Initial reachibility matrix

	1	2	3	4	5	6	7	8	9	10	11	12	Driving power
1	1	1	1	1	1	0	1	1	1	0	0	1	9
2	0	1	0	0	0	0	1	0	1	0	0	1	4
3	0	0	1	0	0	1	1	0	0	0	0	1	4
4	0	0	1	1	0	0	0	0	0	0	0	1	3
5	0	1	1	1	1	0	0	0	0	0	0	1	5
6	1	1	0	1	1	1	0	0	0	0	0	0	5
7	0	0	0	0	0	0	1	0	0	0	1	1	3
8	0	0	0	0	0	0	1	1	1	0	1	1	5
9	0	0	0	0	0	0	0	0	1	1	0	1	3
10	0	1	0	0	0	0	0	0	0	1	0	0	2
11	0	0	0	1	1	0	0	0	1	0	1	1	5
12	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence power	2	5	4	5	4	2	5	2	5	2	3	10	

Table 7: Final reachibility matrix

	1	2	3	4	5	6	7	8	9	10	11	12	Driving power
1	1	1	1	1	1	1*	1	1	1	0	1*	1	11
2	0	1	0	0	0	0	1	0	1	1*	1*	1	6
3	1*	1*	1	1*	1*	1	1	0	0	0	1*	1	9
4	0	0	1	1	0	1*	1*	0	0	0	0	1	5
5	0	1	1	1	1	1*	1*	0	1*	0	0	1	8
6	1	1	1*	1	1	1	1*	1*	1*	0	0	1*	10
7	0	1*	0	1*	1*	0	1	0	1*	0	1	1	6
8	0	0	0	0	0	0	1	1	1	1*	1	1	6
9	0	0	0	0	0	0	0	0	1	1	0	1	3
10	0	1	0	0	0	0	0	0	0	1	0	0	2
11	0	1*	1*	1	1	0	0	0	1	1*	1	1	8
12	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence power	3	7	6	7	6	5	8	3	8	5	6	11	

Table 8: Level partitioning

Barriers	RS	AS	IS	Level
1	1,2,3,4,5,6,7,8,9,11,12	1,3,6	1,3,6	VIII
2	2,7,9,10,11,12	1,2,3,5,6,7,10,11	2,7,10,11	III
3	1,2,3,4,5,6,7,11,12	1,3,4,5,6,11	1,3,4,5,6,11	VII
4	3,4,6,7,12	1,3,4,5,6,7,11	3,4,6,7	II
5	2,3,4,5,6,7,9,12	1,3,5,6,7,11	3,5,6,7	IV
6	1,2,3,4,5,6,7,8,9,12	1,3,4,5,6	1,3,4,5,6	VIII
7	4,5,7,9,11,12	1,2,3,4,5,6,7,8	4,5,7	VI
8	7,8,9,10,11,12	1,6,8	8	VII
9	9,10,12	1,2,5,6,7,8,9,11	9	II
10	2,10	2,8,9,10,11	2,10	I
11	2,3,4,5,9,10,11,12	1,2,3,7,8,11	2,3,11	V
12	12	1,2,3,4,5,6,7,8,9,11,12	12	I

Transitivity Principle

Transitivity is the basic assumption in ISM and is always used in this modelling approach (Watson 1978, Sushil, 2005a; Sushil, 2005b). It also helps in maintaining the conceptual consistency. The final reachibility matrix (Table 7) is derived after the transitivity checking is complete.

Level Partitioning

The final reachibility matrix derived above in Table 7 is now partitioned into different levels. After the first iteration, the barrier classified to level 1 are discarded and the partitioning procedure is repeated on the remaining barriers to determine the level 2. These iterations are continued until the level of each barrier has been determined. The results for iterations 1 to 8 are summarized in Table 8.

Diagraph for modeling the Waste to Energy barriers

Finally the structural model is developed which is called digraph. The analysis yields an ISM hierarchy in which limited community participation and labor conflict is at level 1 (the top level); poor contract management and insufficient public education (second level); wrong selection of waste to energy technology (third level); no benchmarking to assess efficiency of services (fourth level); inadequately trained human resources (fifth level); financial strain on urban local bodies (sixth level); wrong selection of location and poor budget monitoring (seventh level) and poor waste management planning and incomplete legislation and insufficient enforcement (Fig. 1).

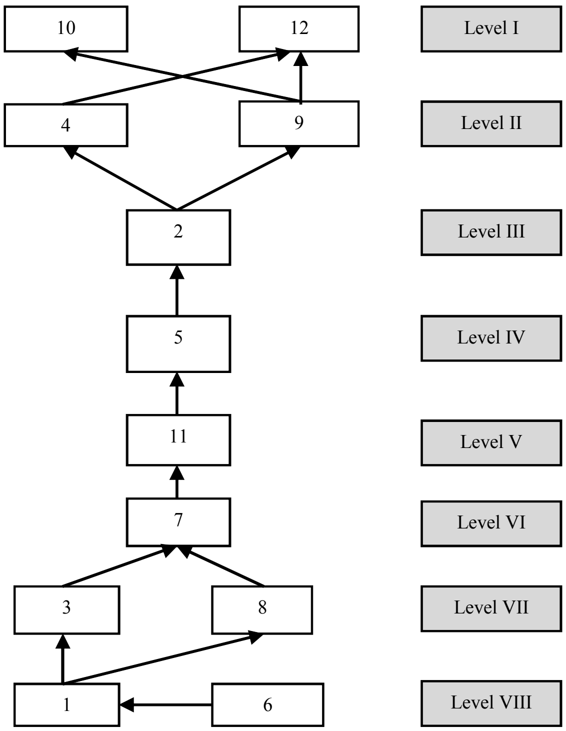

Fig 1: Diagraph of waste to energy barriers

MICMAC Analysis

The purpose of Matrice d'impacts croises multiplication appliqué à un classement (cross-impact matrix multiplication applied to classification) analysis is to analyze the drive power and dependence power of barriers. Based on the drive power and dependence power the barriers have been classified into four categories: autonomous, linkage, dependent and independent factors and presented in Fig 2.

Table 9: Position coordinates

Barriers	Dependence Power (X)	Driving Power (Y)
1	3	11
2	8	6
3	6	9
4	7	5
5	6	8
6	5	10
7	8	7
8	3	6
9	8	3
10	5	2
11	6	8
12	11	1

Table 9 shows the dependence and driving power of key barriers which is derived from final reachibility matrix of ISM steps.

MICMAC analysis

Cluster 1: *Autonomous Factors*

These factors have a weak drive power and weak dependence power. In this cluster we do not have any barrier.

Cluster 2: *Dependence Factors*

These factors have a weak drive power but strong dependence power. In this cluster we have four barriers, i.e, 4 (Poor contract management), 9 (Insufficient public education), 10(Limited community participation) and 12 (Labour conflict).

Cluster 3: *Linkage Factors*

These factors have a strong drive power as well as strong dependence power. In this cluster we have six barriers, i.e., 2 (Wrong selection of Waste to Energy technology), 3 (Wrong selection of Location), 5 (No

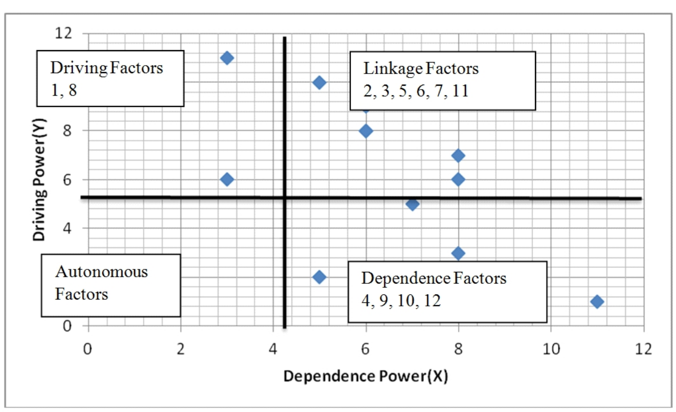

Fig. 2: MICMAC graphical representation

benchmarking to assess efficiency of services), 6 (Incomplete legislation and insufficient enforcement), 7 (Financial strain on urban local bodies) and 11(Inadequately trained human resources).

Cluster 4: *Driving factors*

These factors have a strong drive power but weak dependence power. In this cluster we have two barriers, i.e., 1 (Poor waste management planning) and 8 (Poor budget monitoring).

CONCLUSION

Most of the research conducted so far on solid waste management either focused on the status of solid waste management in different states of India or purely on scientific analysis. Limited studies focused on the managerial aspects of SWM programs or assessed the underlying reasons of such project failures. What is the reason for so many non-functional 'waste to energy' plants in India? The total investment for a single project is over 100 crores. Who is liable for these huge losses? Has anybody pondered over the underlying reasons for closure of these 'waste to energy plants'? India is a developing country and currently starving for energy. Scientists and policy makers are continuously searching for renewable sources of energy to boost the country's growth. During the course of this study several municipalities in West Bengal, Delhi, Andhra Pradesh and Pune was visited to understand the ground reality. Although it was a difficult task to gather the information but authors tried their best to avoid any biasness while collecting the information. It is very surprising to know that certain wrong decisions are killing these important projects which are really required for country's sustainability. It is essential to know the barriers and take proactive action and correct decisions for success of 'waste to energy' projects.

In the present study ISM approach has been employed in finding contextual relationships among the twelve barriers. Finally MICMAC analysis has been performed to categorize different barriers. The driving factors will play an important role in successful solid waste management programs whereas dependent factors characterize desired objectives for achieving success in solid waste management programs. From the analysis 'poor waste management planning' and 'poor budget monitoring' comes under the driving category and overcoming these two barriers will drive the entire SWM project successfully. Under the dependence category comes 'poor contract management', 'insufficient public education', 'limited community participation' and 'labour conflict'. Therefore these characterize the desired objective for achieving success and overcoming these barriers is essential. Also six linkage factors emerged. These Linkage factors are very sensitive and unstable that any action on the factors will trigger an effect on other factors and also a feedback on themselves. Evaluation of different Waste to Energy technologies based on the patterns of energy consumption, production, and different levels of material recovery and on the cost– benefit analysis is necessary to arrive at a suitable technology that will be economically viable and energy efficient. Proper selection of location is equally important from public health perspective. The location should have proper access to vehicles.

The MSW (Management and Handling) rules need to be made tighter. Financial assistance to the ULBs' is important to overcome the challenges. Finally the solid waste management sector must be given the status of an industry so that people involved in this job should feel proud for doing such a great activity for the society.

This study is unique in identifying the 'W to E' barriers and the contextual interrelationships. This study will benefit the policy makers, municipal authorities, state and central pollution control board in taking future decisions in waste to energy projects. More research in this area os required to dig out further and bring out the reality for success of waste to energy projects. The generation of power from such green projects will bring us a cleaner future.

Limitations and future research direction

Every research study suffers from certain limitations and the present study also suffers from few limitations. One drawback is that the ISM model derived may be influenced strongly by the bias of the person who is judging the factors, as the relations among the factors always depends on that person's knowledge and familiarity with the firm, its operations, and its industry. Secondly too many factors make the ISM modeling complex.

The ISM model need to be statistically validated and is also one of our future research directions.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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