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Analysis of interactions among variables of renewable energy projects: A case study on renewable energy project in India

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This study highlights the variables associated with the implementation of renewable energy (RE) projects for sustainable development in India, by using an interpretive structural modeling (ISM) - based approach to model variables' interactions, which impact RE adoption. These variables have been categorized under enablers that help to enhance implementation of RE projects for sustainable development. A major finding is that public awareness regarding RE for sustainable development is a very significant enabler. For successful implementation of RE projects, it has been observed that top management should focus on improving high-driving power enablers (leadership, strategic planning, public awareness, management commitment, availability of finance, government support, and support from interest groups).

Keywords: Enablers, Interpretive structural model (ISM), Renewable energy (RE), Sustainable development

Introduction

Fossil fuels that are depleting very fast account for 79% of energy consumption in the world, and 57% are consumed by transport sector alone[1]. Hence, there is great need to develop alternative energy resources in order to overcome future energy shortage. Indian power sector has shown tremendous growth from 30,000 MW in 1981 to 143,000 MW by March 2008[2]. India has plenty of renewable energy (RE) resources (wind energy, biomass energy, small hydro power and solar energy) to exploit for sustainable development. India is set to reach the aim of meeting 10% of total power supply through renewable energy by 2012[1]. There are many issues and challenges of managing RE sector such as economic feasibility of RE projects are not well established compared to that of fossil fuels, lack of strong regulatory drivers in renewable heat sector compared to electricity market, poor access to capital market, fragmentation of bio-energy R&D funding, lack of skills in resource management, slow adoption of R&D findings by both energy and agriculture industry, poor past economic attractiveness of RE projects that has negative impact on industry perception of the viability of RE solutions, potential public hostility to RE relating to public amenity and a poor understanding of its carbon credentials that could undermine RE deployments and associated industrial R&D[3,4]. Several studies[1,5-9] have identified variables that are associated with implementation of RE projects. Variables are interrelated and relationship depends on characteristics of projects, socio-economic and political environment of projects, and perceptions of managers.

This paper identifies the variables affecting RE implementation projects, besides studying the relationship among them in order to provide effective management of RE projects.

Experimental Section

Variables affecting performance of RE for sustainable development were identified using literature review. A conceptual relationship among variables was made using opinions of experts with respect to a specific RE project. Expert's opinions were gathered through focus group setup and thoughtful discussions among participants[10]. Participants were from academia and industries with more than 15 years of relevant research and / or industry experience. This study adopted Interpretive Structural Modelling (ISM) approach to develop relationship among variables. Warfield[11]

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introduced ISM and Malone[12] conducted its brief review. ISM provides means by which order can be imposed on the complexity of such elements[13,14]. It is an interactive learning process in which a set of different and directly or indirectly related elements affecting the system under consideration is structured into a comprehensive systemic model[15]. ISM has six following steps: Step 1 – Identifying variables affecting performance of renewable energy; Step 2 – Formulating a structural self-interaction matrix (SSIM), which entails pair wise relation of variables; Step 3 – Deriving reachability matrix from SSIM by putting value '1' and '0', which shows pair wise relationship; Step 4 – Devising reachability matrix into different partition levels; Step 5 – Forming ISM model; and Step 6 – Performing MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée á un Classement) analysis[16]. After final ISM structure, MICMAC analysis of variables is done on the basis of their driving and dependence power. MICMAC analysis can be used to categorize variables in a complicated system[17]. Prime function of MICMAC analysis is to examine driving and dependence power of the variables[13]. Basically, elements were divided into four classifications according to their driving and dependence power known as autonomous, linkage, dependent and independent variables[17].

Application of ISM Methodology

The project under study is an upcoming 300 KW small scale combined trigeneration plant having electricity, heating and cooling facilities along with implementing, food processing, cooling and distillation plants in a remote village of West Bengal, India. Project aims to alleviate energy poverty in rural India and improving rural living standard. ISM methodology was applied to identify variables / critical success factors for the project.

Step 1: Identifying Variables Affecting Performance of Renewable Energy (RE)

Studies are available on identifying variables affecting implementation of RE for sustainable development. Beck & Martinot[18] have observed main barriers to RE development in 2004. McCormick & Berger[5] observed major barriers that affect implementation of energy for sustainable development. Himri *et al*[6] has worked on formulating barriers that hinder full potential and advantages of RE. Lidula *et* al[7] has observed barriers to clean and sustainable energy in ASEAN member countries. Mayûeld *et al*[19] has developed a new methodology to deal with barriers affecting the performance of biomass operations. Sharma *et al*[20] has studied parameters of waste management in India. New York State Energy Research and Development Authority and Oak Ridge National Laboratory (ORNL) have identified some barriers to energy through research[15].

An important barrier to RE is lack of leadership qualities in a manager. A good strategic planning identifies RE goals and then formulates policies to manage the goals. Sustainable energy development strategies should deal with energy saving, improvement in the efficiency of energy production and replacement of fossils based oils, coal and gas reserves[8]. Two major factors[21] (technological changes and availability of energy resources) have affected energy pattern the most. As renewable sources are present in abundance, continuing innovation in technology is necessary to harness each form of RE[9]. Major challenge of RE for sustainable development is timely availability of energy resources[8]. Himri *et al*[6] has pointed out that lack of information dissemination leads to lack of support from different stake holders. Shortage of skilled professionals (designers, installers, service & sales representatives, policy analysts, scientists, engineers, teachers and researchers) can affect quality of the system[22]. Government has put lot of efforts to enhance RE use for sustainable development through subsidies and fiscal incentives and has encouraged investors to invest in RE through various relevant policies. Moreover, huge amount of investment is needed in developing high technology. But, longer period of investment increases risk of return on investment[23]. Hence it is necessary to incorporate relevant policies to attract interested group to invest. Market for RE has increased and manufacturers investing huge amount of money in R&D of RET (renewable energy technology), which further lead to sustainable growth economically. Participants decided to consider 14 variables [1 – leadership[7]; 2 – strategic planning[23]; 3 – availability of technology[9,21]; 4 – public awareness[9]; 5 – top management support[6]; 6 – sustainable growth[24]; 7 – return on investment[23]; 8 – availability of finance[1,23]; 9 – skilled manpower[22]; 10 – government support[1]; 11 – availability of data and information[6,8,9]; 12 – availability of energy resources[8,21]; 13 – support from interested groups (stake holders)[6]; and 14 – efficiency of process & execution[8]] affecting performance of RE for concerned project. Finally, in order to have efficient and effective implementation of RE for sustainable

Table 1—Structural self-interaction matrix (SSIM)

Elements	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	V	V	V	V	O	V	V	V	V	A	O	V	V	
2	V	V	V	V	V	V	V	V	V	V	A	V		
3	V	A	O	A	A	A	A	V	V	A	O			
4	O	V	O	V	V	O	V	O	V	V				
5	V	X	V	V	O	V	V	O	V					
6	A	A	A	A	A	A	A	X						
7	A	O	A	A	O	A	A							
8	V	A	V	V	A	V								
9	V	O	O	V	O									
10	O	V	V	O										
11	V	O	V											
12	V	O												
13	V													
14														

Table 2 — Initial matrix

Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	1	1	0	0	1	1	1	1	0	1	1	1	1
2	0	1	1	0	1	1	1	1	1	1	1	1	1	1
3	0	0	1	0	0	1	1	0	0	0	0	0	0	1
4	0	1	0	1	1	1	0	1	0	1	1	0	1	0
5	1	0	1	0	1	1	0	1	1	0	1	1	1	1
6	0	0	0	0	0	1	1	0	0	0	0	0	0	0
7	0	0	0	0	0	1	1	0	0	0	0	0	0	0
8	0	0	1	0	0	1	1	1	1	0	1	1	0	1
9	0	0	1	0	0	1	1	0	1	0	1	0	0	1
10	0	0	1	0	0	1	0	1	0	1	0	1	1	0
11	0	0	1	0	0	1	1	0	0	0	1	1	0	1
12	0	0	0	0	0	1	1	0	0	0	0	1	0	1
13	0	0	1	0	1	1	0	1	0	0	0	0	1	1
14	0	0	0	0	0	1	1	0	0	0	0	0	0	1

development, all 14 variables has to be taken into consideration by managers.

Step 2: Formulating a Structural Self-Interaction Matrix (SSIM)

ISM includes SSIM to represent conceptual interrelationship among various variables, which can be enablers, barriers, and critical success factors. Participants formulated SSIM to demonstrate relation among variables of concerned RE project. Conceptual relation of 'leads to' type is chosen to represent interrelation among variables. Four symbols (V – variable i leads to variable j; A – variable j leads to variable i; X – both variable i and j leads to each other; and O – variables i and j do not lead to each other) are used to describe the direction of relation among variables (Table 1).

Step 3: Deriving Reachability Matrix (RM) from SSIM

SSIM (Table 1) was then transformed into initial RM by converting 4 symbols (V, A, O, X) in to 1 and 0 as per the following rule: i) If (i, j) entry is V in SSIM table, then entry (i, j) in initial RM becomes 1 and (j, i) becomes 0; ii) If (i, j) entry is A in SSIM table, then entry (i, j) in initial RM becomes 0 and (j, i) becomes 1; iii) If (i, j) entry is X in SSIM table, then entry (i, j) in initial RM becomes 1 and (j, i) also becomes 1; and iv) If (i, j) entry is O in SSIM table, then entry (i, j) in initial RM becomes 0 and (j, i) also becomes 0. Initial RM (Table 2) entails interrelationship among variables and some modifications are required to finally improve matrix by including transitivity rule. Initial RM is transformed into final RM (Table 3) by removing transitivity, where transitivity rule says that if

Table 3 — Final matrix

Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	driver
1	1	1	1	0	***1***	1	1	1	1	***1***	1	1	1	1	13
2	***1***	1	1	0	1	1	1	1	1	1	1	1	1	1	13
3	0	0	1	0	0	1	1	0	0	0	0	0	0	1	4
4	***1***	1	***1***	1	1	1	***1***	1	***1***	1	1	***1***	1	***1***	14
5	1	***1***	1	0	1	1	***1***	1	1	***1***	1	1	1	1	13
6	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2
7	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2
8	0	0	1	0	0	1	1	1	1	0	1	1	0	1	8
9	0	0	1	0	0	1	1	0	1	0	1	***1***	0	1	7
10	***1***	***1***	1	0	***1***	1	***1***	1	***1***	1	***1***	1	1	***1***	13
11	0	0	1	0	0	1	1	0	0	0	1	1	0	1	6
12	0	0	0	0	0	1	1	0	0	0	0	1	0	1	4
13	***1***	***1***	1	0	1	1	***1***	1	***1***	***1***	***1***	***1***	1	1	13
14	0	0	0	0	0	1	1	0	0	0	0	0	0	1	3
dependency	6	6	10	1	6	14	14	7	8	6	9	10	6	12	

Table 4—Iteration 1

Elements	Reachability	Antecedents	Intersection	Level
1	1,2,3,5,6,7,8,9,10,11,12,13,14	1,2,4,5,10,13		
2	1,2,3,5,6,7,8,9,10,11,12,13,14	1,2,4,5,10,13		
3	3,6,7,14	1,2,3,4,5,8,9,10,11,13		
4	1,2,3,4,5,6,7,8,9,10,11,12,13,14	4		
5	1,2,3,5,6,7,8,9,10,11,12,13,14	1,2,4,5,10,13		
6	6,7	1,2,3,4,5,6,7,8,9,10,11,12,13,14	6,7	1st
7	6,7	1,2,3,4,5,6,7,8,9,10,11,12,13,14	6,7	1st
8	3,6,7,8,9,11,12,14	1,2,4,5,8,10,13		
9	3,6,7,9,11,12,14	1,2,4,5,8,9,10,13		
10	1,2,3,5,6,7,8,9,10,11,12,13,14	1,2,4,5,10,13		
11	3,6,7,11,12,14	1,2,4,5,8,9,10,11,13		
12	6,7,12,14	1,2,4,5,8,9,10,11,12,13		
13	1,2,3,5,6,7,8,9,10,11,12,13,14	1,2,4,5,10,13		
14	6,7,14	1,2,3,4,5,8,9,10,11,12,13,14		

variable A leads to variable B and B leads to variable C then A will also lead to variable C. Now, a new matrix comes out showing advanced interrelationship among variables. Driving and dependence power of variables is also shown in final RM. Driving power of an individual variable is the total number of variables, which have been influenced by it, or have been achieved by it. For example, driving power of variable 4 (public awareness) is 14, which means variable 4 helps achieve all other variables. Similarly, dependence power of an individual variable is the total number of variables, which leads to individual variable. Dependence power of variable 6 (sustainable growth) is 14, which means all other variables help achieve variable 6.

Step 4: Devising Reachability Matrix (RM) into Different Partition Levels

These iterations (Tables 4-6) were developed from final RM (Table 3). Reachability and antecedents of variables were derived from final RM[11]. Reachability set of a particular variable represents its driving power, and is the total number of variables achieved by it. Similarly, antecedent set of a particular variable represents dependence power of a variable, and is the total number of variables, which help in achieving it. Interaction set of reachability and antecedent set was then formulated. If intersection set of a variable consists of same elements as of reachability set then that variable is ranked at the top in ISM hierarchy and does not lead to other variable

Table 5—Iteration 2

Elements	Reachability	Antecedents	Intersection	Level
1	1,2,3,5,8,9,10,11,12,13,14	1,2,4,5,10,13		
2	1,2,3,5,8,9,10,11,12,13,14	1,2,4,5,10,13		
3	3, 14	1,2,3,4,5,8,9,10,11,13		
4	1,2,3,4,5,8,9,10,11,12,13,14	4		
5	1,2,3,5,8,9,10,11,12,13,14	1,2,4,5,10,13		
6				
7				
8	3,8,9,11,12,14	1,2,4,5,8,10,13		
9	3,9,11,12,14	1,2,4,5,8,9,10,13		
10	1,2,3,5,8,9,10,11,12,13,14	1,2,4,5,10,13		
11	3,11,12,14	1,2,4,5,8,9,10,11,13		
12	12,14	1,2,4,5,8,9,10,11,12,13		
13	1,2,3,5,8,9,10,11,12,13,14	1,2,4,5,10,13		
14	14	1,2,3,4,5,8,9,10,11,12,13,14	14	2nd

Table 6—Iteration 7

Elements	Reachability	Antecedents	Intersection	Level
1	1,2,5,10,13	1,2,4,5,10,13	1,2,5,10,13	7th
2	1,2,5,10,13	1,2,4,5,10,13	1,2,5,10,13	7th
3				
4	1,2,4,5,10,13	4		8th
5	1,2,5,10,13	1,2,4,5,10,13	1,2,5,10,13	7th
6				
7				
8				
9				
10	1,2,5,10,13	1,2,4,5,10,13	1,2,5,10,13	7th
11				
12				
13	1,2,5,10,13	1,2,4,5,10,13	1,2,5,10,13	7th
14				

above their own level. After ranking of a variable, it has been removed from iteration table and similarly further iterations are carried out till the ranking of each variable is taken out. In this way, one gets hierarchy of variables according to their driving and dependence power, which are further formulated into ISM model. From first iteration (Table 4), variable 6 (sustainable growth) and 7 (return on investment) stood at the top level. Similarly, all variables are ranked and placed at their respective levels.

Step 5: Forming ISM Model

ISM was finally formulated (Fig. 1) with the help of final RM and level partitions. Ranking of all variables is known through level partitions so they have been put at their respective levels in ISM hierarchy. Now, if variable (i, j) are in relation with each other then it is shown by arrow pointing from i to j or from j to i, depending on their interrelationship as stated in final RM. Finally, resultant graph is known as a digraph. After formulation of digraph, transitivity's are removed from digraph and it is transformed into ISM based model by converting variable nodes into statements.

It is observed from ISM based model that public awareness on RE was very important variable as it has highest driving power and zero dependence power. This means that this variable is very significant and drives all other variables. So, policy maker has to keep more focus on public awareness to implement RE for sustainable development successfully[25].

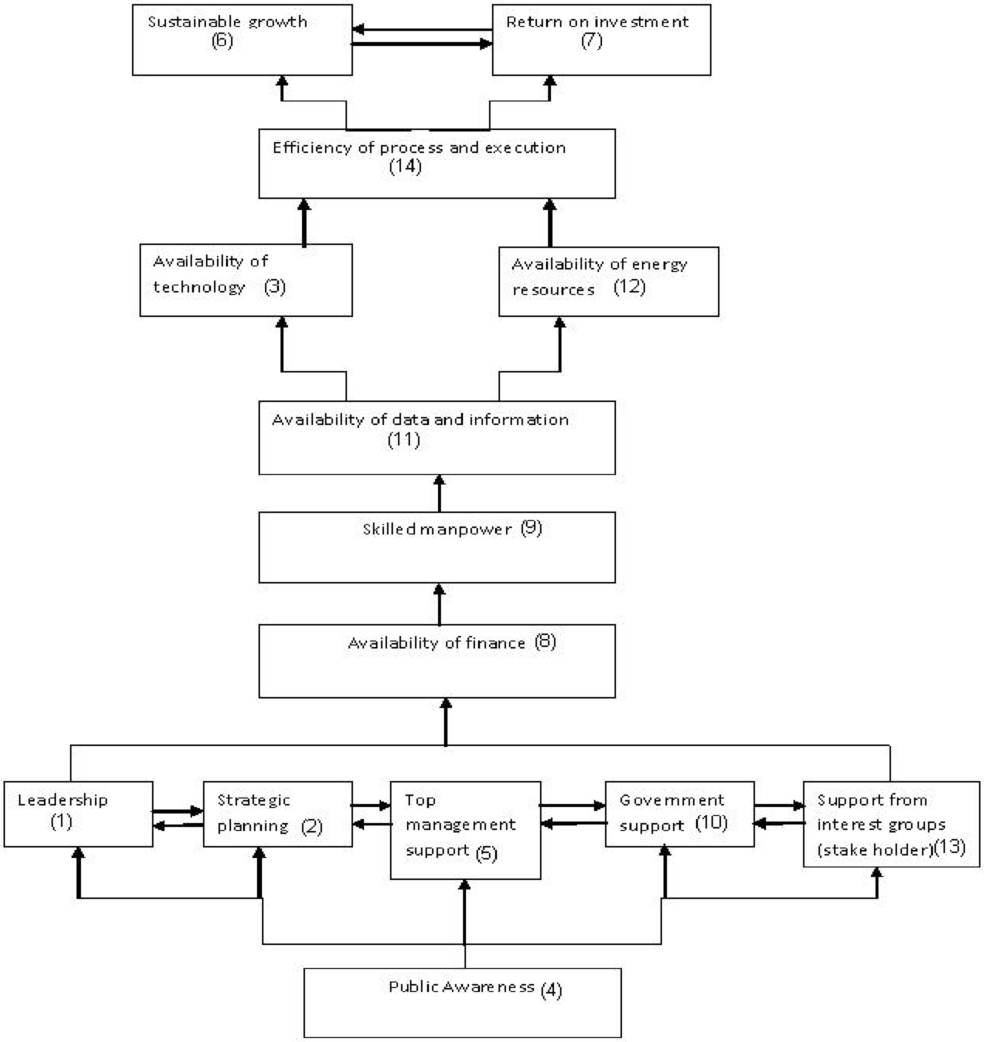

Fig. 1—ISM based model

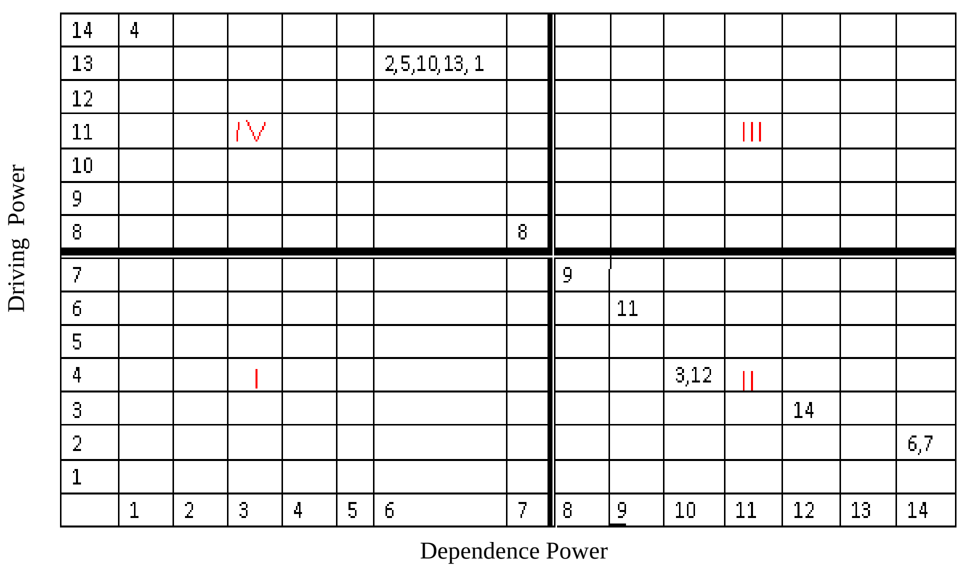

Fig. 2—MICMAC analysis

Step 6: MICMAC Analysis

MICMAC analysis was carried out to categorize variables according to their driving and dependence power. In MICMAC diagram (Fig. 2), columns represent dependence and rows driving power. All variables have been placed according to their driving and dependence power. As for example, variable 4 (public awareness) has driving power of all 14 variables and dependence power of 1 (self). Therefore, it has been placed accordingly in MICMAC diagram at the extreme left and at the topmost place. First cluster is known as autonomous barrier, which has very weak driving power and simultaneously has weak dependence power. These variables mostly have no connection with the system or with other variables; they only share few links that can be strong. Second cluster is known as dependent barrier, which consists of variables having weak driving power and strong dependence power. These variables mostly depend on other variables so; any action on other variables will affect dependent variables. Third cluster consists of linkage variables, which have strong driving and strong dependence power. These variables are highly unstable so, any action on these variables will affect other variables and also have a feedback on them. Fourth cluster is basically independent barrier, which have strong driving power and weak dependence power.

Discussion & Conclusions

This study identified variables known as 'enablers for RE', and developed interrelationships among variables using ISM methodology. From ISM based model, variable 4 (public awareness) is of top most priority as it has highest driving power of 14 and lowest dependence power of 1. This also states that policy makers have to create public awareness on the use of RE for sustainable development[25]. As awareness on RE among public will lead to top management support (variable 5). Leadership (variable 1) qualities of a manager can act as a tool only if there is a top management support. Good strategic planning (variable 2) needs leadership quality of a manager and incentive support from top management. Support from interested groups (variable 13) cannot be there if there is no top management support with policy makers. Availability of finance (variable 8) is ensured by the support from interest group (stake holder). Skilled manpower (variable 9) and availability of information is very necessary for successful implementation of RE projects for sustainable development. Availability of finance actually helps in achieving skilled manpower as nowadays skilled manpower is highly cost intensive. Information management (variable 11) ensures effective utilization of resources. Lack of appropriate data and information will lead to lack of interest of public and management, which further lead to lack of energy resources (variable 12) and lack of RET (variable 3). Outdated technology has a direct impact on efficiency of the process and its execution (variable 14). So, more and more money should be invested in development of higher technologies for successful implementation of RE projects. Higher and higher efficiency of the process will lead to sustainable growth (variable 6), which further leads to return on investment (variable 7) or vice versa. Good return on investment is symbol of a sustainable growth. This study shows that all variables are enablers, which basically enable successful implementation of project. So, there is great need to work upon these variables according to ISM hierarchy for sustainable development through RE sources.

In MICMAC analysis, there are no autonomous variables, which prove that all variables influence implementation of RE for sustainable development. S imilarly, there are no variables in third cluster, which is linkage barriers, indicating that all variables are stable. Variables [leadership, strategic planning, public awareness, top management support, availability of finance, government support, and support from interest groups (stake holder)] fall under fourth cluster, which is independent barrier. All these variables have high driving power and policy makers should focus more on these variables as they affect or influence other variables. Other variables (availability of technology, availability of data and information, sustainable growth, return on investment, skilled manpower, availability of energy resources and efficiency of process) fall under second cluster and have high dependence power. ISM based model represents an overall picture of the problems in implementing RE projects. This research has most importantly identified variables affecting implementation of RE project and their interrelationship for the project under study. This model helps making decisions more efficiently.

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