APPLICATION OF INTERPRETATIVE STRUCTURAL MODELLING FOR IDENTIFYING CRITICAL FACTORS IN SUSTAINABLE ENERGY PLANNING HYDROPOWER PROJECTS

Goran Orašanin[1], Budimirka Marinović[2*], Stojan Simić[1], Uroš Karadžić[3]

[1] Faculty of Mechanical Engineering, University of East Sarajevo, Vuka Karadžića 30, 71123 East Sarajevo, Bosnia and Herzegovina
[2] Faculty of Production and Management Trebinje, University of East Sarajevo, Stepe Stepanovica bb, 89101 Trebinje, Bosnia and Herzegovina
[3] Faculty of Mechanical Engineering, University of Montenegro, Džordža Vašingtona bb, 81000 Podgorica, Montenegro

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Abstract

The interest in small hydropower plant (SHP) as renewable energy is increasing but also selecting the appropriate small SHP project and its parameters involve different factors because of the multi-dimensionality of sustainable development goals. Number of studies have examined different aspects (environmental, technical, economic ...), no prior study has delved into their interactions. To fill these gaps this paper presents the analysis of interrelationship among criteria for sustainable planning project solutions in construction of SHP. The criteria were identified through a review of the literature, as well through the advice of experts in the access areas. Contextual relationships among these criteria have been identified and Interpretative Structural Modelling (ISM) technique and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) analysis has been developed. ISM was used to identify hierarchical structure of all factors while MICMAC analysis has been used to classify criteria based on their dependence and driving power. The main goal of this study is to establish a theoretical and methodological approach for decision makers to investigate influencing factors and major insights into relationship between. The analysis results reveal that criteria Flow pattern and amount of flow, Annual flow and Installed capacity are all key drivers of the desire to realize sustainable SHP project.

1 Introduction

Energy has a significant and important role in the development of the economy. Accelerated development of the economy requires increasing energy consumption and also this means increasing pressure on the environment [1]. The excessive use of fossil fuels, especially in the energy sector, has been one of the important topics related to global warming in recent decades and all countries strive to participate in reducing carbon emissions [2]. Therefore, increasing efforts are being made to reduce carbon and other greenhouse gas emissions through the use of renewable energy sources.

Increasing the share of electricity production from renewable energy sources is an obligation and imperative in many countries.

Hydropower as one of the most important renewable energy sources is also considered as clean energy [3]. and only one that is economically competitive with fossil fuels and nuclear energy. In addition to economic, the advantage of hydropower is significantly reduced or no adverse impacts on the environment. Despite its advantages hydropower is not completely safe for the environment, and it is not as clean as it is presented [4].

* Corresponding author
E-mail address: budimirka.marinovic@fpm.ues.rs.ba

SHP have a minimal impact on climate, but they are often built in protected areas with high natural diversity and richness. Although it is often emphasized that the untapped potential of rivers, their construction involves also some challenges and pressure from environmental groups, as well as from the local community and investors [5]. On the other hand, the construction of SHP and the energy that can be obtained from them is certainly not negligible, and paying attention to their importance is justified [6]. Investors mostly pay attention only on economic aspects, but the impact of construction in protected areas, ecosystem disturbances, degradation of the living environment [7] and ensuring the satisfaction of the local population, the local community has mostly been neglected. SHP projects should be realized in an environmentally friendly and socially acceptable manner. The imperative of sustainability demands is that every decision – making process in building and designing hydropower system, analyse environmental, political, historical, cultural and other social impacts, beside the normal technical and economic concerns [8] and to green the overall SHP project minimizing its impact [4].

Preceding studies have used various multi-criteria decision methods as they can be helpful support to achieve sustainable solution [9]. For instance, [9] used multi-criteria analysis to define environmental flows to be released by SHP. The combination of Promethee and Analytic Hierarchy Process (AHP) was proposed by Gvozdenac Urošević and Marinović to develop a model for ranking SHP projects.

Most of these studies are mainly focused on the criteria and different aspect. However, the relationship between analysed criteria (factors) is missing. Therefore, the main goal in this paper is to represent the interrelationships among elements in sustainable SHP project constructions. Studying criteria helps to arrive at the sustainable objectives for projects [10]. The paper firstly reviews elements (criteria) which must be considered in sustainable energy projects; secondly discuss the ISM methodology; thirdly it uses interpretative structural modelling and MICMAC analysis to develop analytical framework, and at the end highlights the factors and discuss the obtained relationship. All criteria are divided in four main criteria groups: engineering, economic, environmental and social. They have been identified through literature review and the expert suggestions. The ISM and MICMAC approach helps to analyse the relationship between various criteria along with their driving and dependencies power [11]. The study may offer direction to the stakeholders to improve overall SHP projects, and to improve knowledge of how the criteria relate to one another and to develop a hierarchy form.

2 Research Methodology

All participants have different expectations from project. The present study aims to identify the criteria for evaluating the construction of SHP, in order to establish a relationship between the criteria by applying ISM technique. A review of the literature found that for the selection location for the construction of the SHP in the largest number of studies uses the four main criteria groups: engineering, economic, environmental and social. Through the further research, 15 criteria were singled out, and at the suggestion of experts, 1 more criterion is added, so that the total number of criteria for analysis is 16. In the next step, the ISM methodology was applied to determine the interrelationships of the criteria. For these criteria the ISM methodology is clearly presented in the principle of step-by-step model development. After generating the ISM, the result is integrated into a MICMAC analysis to investigate and to understand the degrees of interactions between the criteria.

2.1 Criteria in sustainable energy planning

Evaluation criteria and methods that reliably measure sustainability is a prerequisite for selecting the best alternative [12]. Criteria for assessment energy systems are mainly divided to a: technical, economic, environmental and social criteria. The literature contains several examples of studies that have used different criteria for in sustainably energy projects. The studies [12-17] has been used for formulating the criteria in this study.

In addition to the criteria identified by the literature review, the authors also consulted experts in the field of renewable energy sources whose narrow specialty is hydropower. Through discussions and consultations with expert (with academic background in field of hydroelectric plant) the authors expanded the list of criteria obtained from the literature with one new criterion. According to these 16 related factors were found comprising 5 engineering, 4 economic, 4 environmental and 3 socio-economic criteria. Summarized and described criteria are shown in Table 1.

Table 1.: Systematic Literature review of criteria

Dim	Criteria		Description	References
ENGINEERING ASPECT	A1	Installed capacity	Capacity of the hydro power plant (HPP) that works with installed discharge and net head.	Waisurasingha et al., 2012; Supriyasilp et al., 2009
	A2	Annual energy production	Indicates the potential for generating electrical energy per year	Waisurasingha et al., 2012; Supriyasilp et al., 2009
	A3	Length of transmission line	The distance from the HPP location to the electricity distribution system.	Waisurasingha et al., 2012; Supriyasilp et al., 2009
	A4	Net capacity factor	It is defined as the ratio of actual output in HPP over a period of time, to its potential output.	Expert opinion
	A5	Annual flow	Amount of annual flow is a major factor for calculating annual energy production.	Supriyasilp et al., 2009
ECONOMICAL ASPECT	B1	Internal rate of return (IRR)	Indicates the profitability of project for potential area.	Waisurasingha et al., 2012
	B2	Project cost	Indicates the budget for set up the HPP project.	Supriyasilp et al., 2009
	B3	Electricity generating cost (EUR/kWh)	Based on the average expected annual production of energy, this is a better indicator than EUR/kW because it takes into account the expected river flow rate.	Supriyasilp et al., 2009
	B4	Payback period	It refers to the period of time required for the return of investment.	Mourmouris, Potolias, 2013;
ENVIRONMENTAL ASPECT	C1	Dust and noise during site construction	Depending on the length of the construction period disrupts the activity of life.	Waisurasingha et al., 2012
	C2	Flow pattern and amount of flow	This factor have important implications for the river ecosystem. It indicates how much water remains in river after construction of hydropower plant.	Supriyasilp et al., 2009
	C3	Land use	The environment affected by the land occupied by whole system of SHP	Wang et al., 2009
	C4	GH emission reduction	Refers to the total amount of greenhouse gases avoided	Mourmouris, Potolias, 2013;
SOCIO-ECONOMIC ASPECT	D1	Water resource problem	Indicating on lack of water for agriculture, or problems related to accessibility to water resources.	Waisurasingha et al., 2012; Supriyasilp et al., 2009
	D2	Social aceptability	It indicates the citizens' acceptance of the project.	Wang et al., 2009; Tsoutsos et al., 2009
	D3	Contribution to local development and welfare	Rate the total socio-economic impact	Tsoutsos et al., 2009

3 ISM for identifying critical factors in sustainable energy planning hydropower projects

ISM was first proposed by Warfield in 1973, to analyse the complex system [18-20]. ISM is an interactive process in which a set of directly and indirectly related elements is hierarchically organized for a specific case [21]. The application of ISM methods helps in understanding the interrelationships between the criteria. Also, it helps in extracting the most important criteria, with the help of ISM digraph and MICMAC analysis [22].

The ISM methodology is represented in a large number of research papers. Attri 2017 [19] states that there is a wide range of applications of the ISM approach, and categorizes the applicability of the ISM methodology into ten areas, including energy management. Furthermore, Ansari et al. [23] applied this method to analyse barriers into implementing solar installations in India, and Sindhu et al. [24] to identify and analyse barriers to implementing solar energy in rural India. It has been used in supply chains in the oil and gas industry [25]; in determining key criteria for the development of renewable energy in Indonesia [2]; in energy efficiency analysis [26, 27]; in the analysis of the impact on the development of electricity generation projects from renewable sources in China [28]; to the assessment of the strategy for the development of renewable energy in Rwanda [29], and in determining sustainable resource management in the Bengkul hydroelectric basin [30].

The procedural steps of ISM development are [19, 22, 31]:

I. Identification the criteria related to the problem. The criteria can be identified through literature research, suggestions from experts of academic institutions and industry, as well as conducting a survey based on questionnaires for interest groups.

II. Establishing a contextual relationship between the identified criteria from the first step.

III. Development of Structural self-interaction matrix (SSIM) based on the contextual relationship (V, A, X, O) between the criteria defined in step II.

IV. Development of initial reachability matrix (IRM). In this step the SSIM (contextual matrix form) is changed to a binary matrix by replacing V, A, X and O to 1 or 0.

V. Development of final availability matrix.

VI. Levels partitioning - subchapter in results and discussion partitioning of the levels of the Final reachability matrix (FRM), i.e. Reachability set, Antecedent set and Intersection Set are derived from the FRM to be divided into different levels. The procedure for each criteria is performed as follows [18]:

- A reachability set is calculated so that it consists of the criterion itself as well as other criteria that can affect those criteria.
- The previous set (Antecedent set) is calculated so that it consists of the criteria itself and other criteria that can affect those criteria.
- A set of intersections (Intersection Set) is calculated.

After calculating the Reachability set, Antecedent set and Intersection Set, criteria with a similar Reachability set and Intersection Set occupy the highest level in the ISM model and they do not affect other criteria above their own level. In order to identify the next level, the criteria identified at the higher level are eliminated from the further procedure and analysis of the ISM model. In this way, the criteria of the next level are identified. This procedure continues until the level of all criteria is identified.

VII. Development of cone matrix (CM) from the FRM, which is used to develop the diagram. The principle is to merge all elements of the same level that are identified in the level partitioning, across rows and columns. The cone matrix has the values "0" in most of the upper elements of the triangle and the value "1" in the lower elements of the triangle.

VIII. Development of digraph. A digraph graphically displays the directionality of criteria relationships and a hierarchy of levels to show direct relationships.

IX. Development of ISM model by replacing the nodes with criteria.

X. MICMAC analysis. The objective MICMAC analysis is to understand the nature of each criterion by grouping them into four clusters. Each criterion will be classified into one of these four group and in this way the filtering of the criteria can be done more easily.

3.1 Structural self-interaction matrix (SSIM)

For selected criteria a contextual relationship is established using SSIM: direction of relationship between criteria *i* and criteria *j*. Table 2 shows SSIM developed for the problem under consideration. Guidelines for filling the X_{ij} spaces in the response matrix are:

V - if *i* is responsible to achieve *j* (factor *i* will help to achieve factor *j*);
A - if *j* is responsible to achieve *i* (factor *i* will be achieved by factor *j*)
X - if both *i* and *j* are related together equally (factors *i* and *j* will help to achieve each other)
O- if *i* and *j* are unrelated (factors *i* and *j* are unrelated).

Following a discussion of the results with stakeholders in sustainable energy planning (university professor, co-owner of the SHP, representatives from from Power Utility, Regulatory commission for Energy, Centre for Environment and Electricity Distribution Company) a SSIM was developed for selected criteria.

Table 2. Structural self-interaction matrix

	D3	D2	D1	C4	C3	C2	C1	B4	B3	B2	B1	A5	A4	A3	A2	A1
A1	V	O	V	V	V	A	O	V	V	V	V	A	O	O	V	
A2	V	O	V	V	O	A	O	V	V	V	O	A	O	V		
A3	O	O	O	O	V	A	V	V	O	V	O	O	O			
A4	V	O	O	V	O	O	O	V	V	V	V	A				
A5	V	O	V	V	O	A	O	V	V	O	V					
B1	O	O	O	V	V	A	O	V	V	V						
B2	O	O	O	O	A	A	O	V	O							
B3	O	O	O	O	O	A	O	V								
B4	O	O	O	O	A	A	O									
C1	O	V	O	V	A	A										
C2	O	V	V	V	V											
C3	O	V	O	O												
C4	O	V	O													
D1	V	O														
D2	A															
D3																

3.2 Reachability matrix

The SSIM is transformed into a binary format 0 or 1 called as initial reachability matrix (IRM) adopting the following rules [21].

Table 3: Rules for formating initial reachability matrix

SSIM matrix	IRM matrix	
Xij	Xij	Xji
V	1	0
A	0	1
X	1	1
O	0	0

The final reachability matrix given in Table 4 has been prepared by incorporating the transitive rule [32]. According to this in the initial availability matrix, the values 1* include the concept of transitivity as a basic assumption in the ISM approach. The transitivity of the contextual relationship is a basic assumption made in ISM and it states that if variable *X* is related to variable *Y* and variable *Y* is related to variable *Z*, then variable *X* is necessarily related to variable *Z* [23].

Table 4. Final reachability matrix

Criteria		1 A1	2 A2	3 A3	4 A4	5 A5	6 B1	7 B2	8 B3	9 B4	10 C1	11 C2	12 C3	13 C4	14 D1	15 D2	16 D3	**Driving**
1	A1	1	1	1*	0	0	1	1	1	1	1*	0	1	1	1	1*	1	**13**
2	A2	0	1	1	0	0	0	1	1	1	1*	0	1*	1	1	1*	1	**11**
3	A3	0	0	1	0	0	0	1	0	1	1	0	1	1*	0	1*	0	**7**
4	A4	0	0	0	1	0	1	1	1	1	0	0	1*	1	0	1*	1	**9**
5	A5	1	1	1*	1	1	1	1*	1	1	0	0	1*	1	1	1*	1	**14**
6	B1	0	0	0	0	0	1	1	1	1	1*	0	1	1	0	1*	0	**8**
7	B2	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	**2**
8	B3	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	**2**
9	B4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	**1**
10	C1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	**3**
11	C2	1	1	1	1*	1	1	1	1	1	1	1	1	1	1	1	1*	**16**
12	C3	0	0	0	0	0	0	1	0	1	1	0	1	1*	0	1	0	**6**
13	C4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	**2**
14	D1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1*	1	**3**
15	D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**1**
16	D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	**2**
Depend.		**3**	**4**	**5**	**3**	**2**	**5**	**9**	**7**	**11**	**7**	**1**	**8**	**10**	**5**	**13**	**7**	

3.3 Levels partitioning

The partitioning of the reachability matrix is done by evaluating the reachability set and the antecedent set for each criterion [18]. Therefore, for each criterion, the analysed criterion and other criteria from the row of the analysed criterion with the value 1 are entered from the reachability matrix into the reachability set. For each criterion, the analysed criterion and other criteria from the column of the analysed criterion with the value 1 are entered from the reachability matrix into the antecedent set [33]. After forming the reachability set and antecedent set, the intersection of the sets for each criterion is determined. The identified levels for each criterion resulted in nine levels for the 16 criteria and are shown in Table 5.

Table 5: Levels of criteria in sustainable energy planning SHP

Criteria	Reachability set	Antecedent set	Intersection	Level
1	1,2,3,6,7,8,9,10,12,13,14,15,16	1,5,11	1	VII
2	2,3,7,8,9,10,12,13,14,15,16	1,2,5,11	2	VI
3	3,7,9,10,12,13,15	1,2,3,5,11	3	V
4	4,6,7,8,9,12,13,15,16	4,5,11	4	VII
5	1,2,3,4,5,6,7,8,9,12,13,14,15,16	5,11	5	VIII
6	6,7,8,9,10,12,13,15	1,4,5,6,11	6	V
7	7,9	1,2,3,4,5,6,7,11,12	7	II
8	8,9	1,2,4,5,6,8,11	8	II
9	9	1,2,3,4,5,6,7,8,9,11,12,	9	I
10	10,13,15	1,2,3,6,10,11,12	10	III
11	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	11	11	IX
12	7,9,10,12,13,15	1,2,3,4,5,6,11,12	12	IV
13	13,15	1,2,3,4,5,6,10,11,12,13	13	II

14	14,15,16	1,2,5,11,14	14	III
15	15	1,2,3,4,5,6,10,11,12,13,14,15,16	15	I
16	15,16	1,2,4,5,11,14,16	15	II

3.4 Conical matrix

Developing a lower triangular or conical matrix allows a clear representation of the hierarchical impact of each criterion [33, 34]. Criteria levels obtained by iterations in partitioning levels through Reachability set, Antecedent set and Intersection, can be converted into a conical matrix [33]. Conical matrix or A lower triangular matrix is developed by grouping criteria across rows and columns, according to the identified level [35]. The value of the upper elements of the triangle in the conical matrix is mostly "0", while the value of the lower elements of the triangle in the conical matrix is mostly "1".

The picture 1 shows the hierarchical division of the criteria according to the level they occupy (9 levels) as well as the direct links in the relations of the criteria. Direct links are shown with an arrow, ie. if there is a relationship between the criteria, those criteria are connected with an arrow.

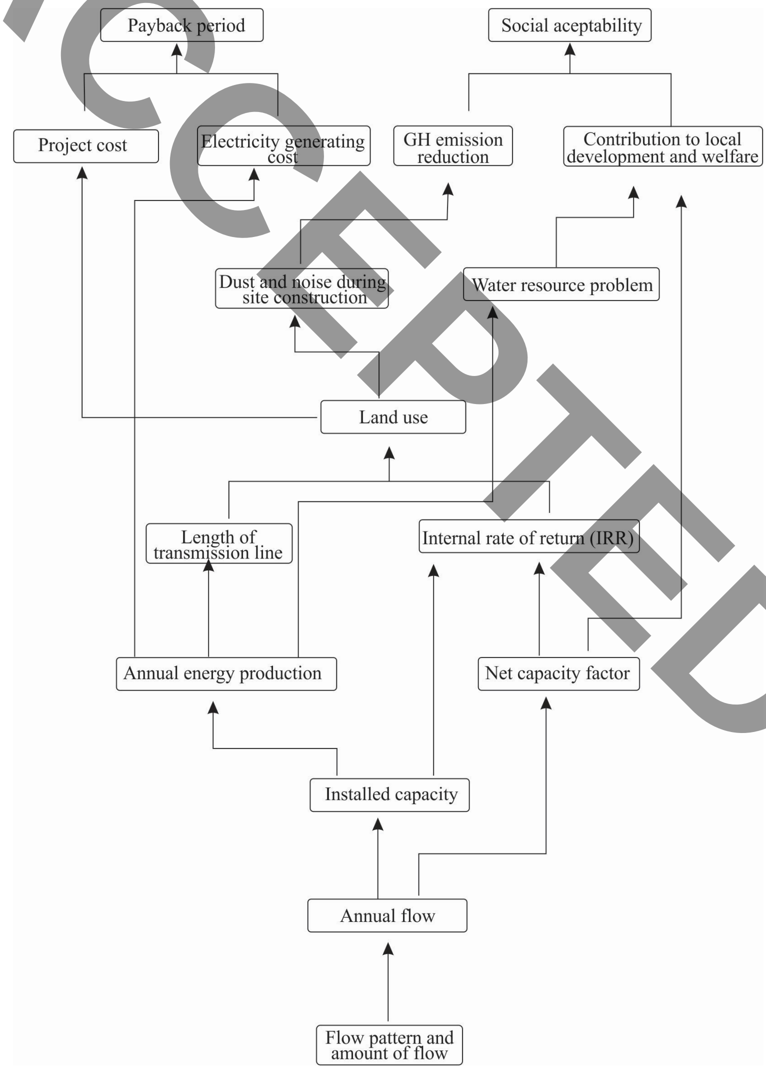

Figure 1: Digraph depicting the relationship among criteria

3.5 MICMAC analysis

MICMAC analysis analyses the dependence power and driving power (Table 5, Figure 1) criteria. It is done to identify the key criteria that drive the system in various categories, and filtered dependent criteria.

Based on their dependence and driver power, the criteria are classified into four clusters: autonomous, dependent, linkage and driver/independent. The autonomous criteria have weak driver and weak dependence power. These criteria are disconnected from the system, they can have few links with system, and they may be strong. The dependent criteria have weak driver, but strong dependence power. The linkage criteria have both driver and dependence power, very strong. These criteria are unstable due to the fact that any action on these elements will affect the others and also feedback on themselves. It can be concluded that the key criteria with strong driver power are into the category of independent or linkage elements [36]. Figure 2 shows the criteria arranged in 4 clusters.

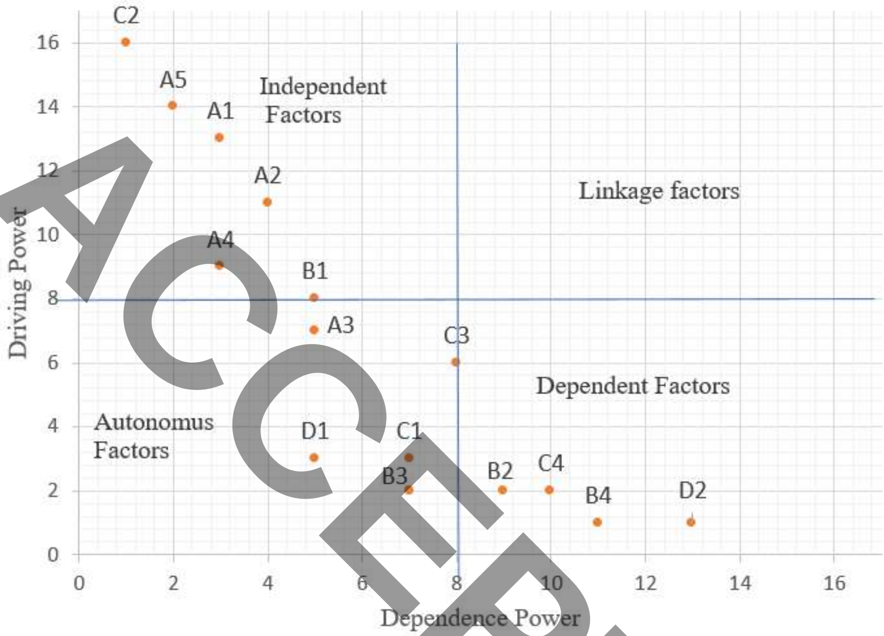

Figure 2: MICMAC Analysis

4 Discussion

Efficient energy planning in energy sector is important step toward sustainable development. The ranking structure of 16 key criteria and MICMAC visual presentation are basic keys [11] to understand how these criteria interact and what is their role on sustainable SHP energy planning.

Based on Figure 1 and Figure 2, that is, the graph and MICMAC analysis, it can be concluded that the greatest driving force have criteria Flow pattern and amount of flow (C2), Annual flow (A5), Installed capacity (A1), Annual energy production (A2) and Net capacity factor (A4) and belong to environmental and engineering aspects. In Figure 1, the ecological aspect for the preservation of the ecosystem is particularly highlighted, and the engineering aspect with Annual flow and Installed capacity, which have weak dependence and significant driving force and are contained as drivers in most other criteria. Maintaining the ecosystem in relation to the Annual flow (A5), Installed capacity (A1) and Annual energy production (A2) will significantly affect the planning or design of the SHP, but also satisfy different interest groups. The criterion Internal rate of return (B1) of the economic aspect stood out on the border of the autonomous and independent cluster. Social acceptability (D2), Payback period (B4), Greenhouse gas emission reduction (C4) and Project cost (B2) are having low driving power and high dependence power. Project costs (B2) and payback period (B4) are dependent criteria of the economic aspect with which investors most often decide on the investment. However, Social acceptability is also imposed as an investment risk. These criteria depend on the criteria Flow pattern and amount of flow (C2), Annual flow (A5) and Installed capacity (A1). This clearly indicates that if the planning, design or construction of SHP is based only on dependent criteria, then one enters the risk zone of its construction. That risk zone implies either that SHP is not built at all or that it is built with environmental damage, which is by no means acceptable.

Autonomous criteria have a weak driving force, as well as a weak dependence, and in this regard, they do not have much influence on the planning and design of mini hydropower plants. Autonomous criteria are

Length of transmission line (A3), Water resource problem (D1), Dust and noise during site construction (C1), Electricity generating cost (EUR/kWh) (B3) and Contribution to local development and welfare (D3).

The criterion Land use (C3) of the aspect of environmental protection stood out at the border of the first and second cluster, that is, at the border of the autonomous and dependent cluster. Based on the graph, it can be determined that this criterion is dependent on five driving and two automatic criteria, and as such it can be classified as autonomous criteria.

The study has certain limitations that mast be considered. The ISM model is based on authors and expert views which can be baized on their personal judgments [37]. Also, the ISM model is based on 16 criteria which are mainly based on study of literature, this may be not comprehensive list of criteria, and future studies should explore some other criteria for sustainable energy projects and strategies.

5 Conclusion

The study presents the ISM approach and provides a focused methodology for identifying critical criteria in sustainable development SHP projects. 16 criteria were identified through a review of the literature and consultations with experts, and relationships between those criteria were established. The presented model provides the inter relationship among criteria for better SHP projects construction. Based on the identification of the level of criteria, the dependencies of the criteria on each other were graphically displayed by creating a graph. The MICMAC analysis established the affiliation of the criteria to a certain cluster, which creates a clear picture of the criteria by which decisions are made.

The ISM analysis showed that decisions for the selection, planning, design and construction of a SHP should not be made solely on the basis of dependent criteria such as investment, return on investment or social acceptability. As driving criteria, i.e. criteria on which these criteria depend to a large extent, it clearly shows that the power of choice can be determined by optimal solutions, to satisfy the river ecosystem based on annual flows, ensure safe energy production and satisfy social acceptability. As sustainable strategies are essential for sustainable development studying critical success criteria in SHP projects play a significant role in arriving the project success. The approach implemented in this study can help decision-makers, investors and managers in SHP projects decision and promote sustainable goals instead of short-term economy profits ones.

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