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Author(s)	Contreras, Sergio; Finnerty, Noel; Sterling, Raymond; Coakley, Daniel; Keane, Marcus M.
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A Systematic Decision Support Framework and Prioritization Method for Energy Projects in Industrial Organisations

SERGIO CONTRERAS, NOEL FINNERTY, RAYMOND STERLING, DANIEL COAKLEY & MARCUS M. KEANE

Abstract This paper describes a decision support framework to help industrial organisations make positive investment decisions on energy performance improvement projects. It is intended as a simple and repeatable approach for energy managers to promote informed, unbiased energy-related decision-making from top management. The framework is underpinned by a project prioritisation tool that uses economic, environmental, social and technical criteria. This tool is a hybrid multi-criteria decision method that combines Analytical Hierarchy Process, Fuzzy Logic and Technique for Order of Preference by Similarity to Ideal Solution. The proposed methodology is applied in a case study concerning five energy projects in a Fortune 500 manufacturing corporation in the life sciences industry. Results show the application of this decision support framework resulted in increased funding for energy projects within this large organisation.

Keywords: • Energy • energy management • project prioritisation • decision-making method • ISO-50001 •

CORRESPONDENCE ADDRESS: Sergio Contreras, College of Engineering and Informatics, IRUSE, Ryan Institute, NUI, Galway, Ireland, email: sdcontrerasg@gmail.com. Noel Finnerty, Boston Scientific Corporation, Ballybrit Business Park, Galway, Ireland, email: Noel.Finnerty@bsci.com, Raymond Sterling, PhD, Researcher, College of Engineering and Informatics, IRUSE, Ryan Institute, NUI, Galway, Ireland, email: raymond.sterling@nuigalway.ie. Daniel Coakley, PhD, College of Engineering and Informatics, IRUSE, Ryan Institute, NUI, Galway, Ireland, email: danielcoakley1@gmail.com. Marcus M. Keane, Lecturer, College of Engineering and Informatics, IRUSE, Ryan Institute, NUI, Galway, Ireland, email: Marcus.keane@nuigalway.ie.

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1 Introduction

In implementing energy management, organisations align to standards such as ISO-50001 aimed at improving energy performance. These standards require implementing organisations to develop and prioritise energy performance improvement projects. However, specific guidelines for such prioritisation are missing, resulting in organisations having to create bespoke solutions. For industrial firms, including non-energy intensive multi-site organisations[1] with operations across a network of sites, this ad-hoc approach may result in both, under-investment and non-optimal or biased investment decisions. This has been highlighted in literature as a contributing factor to the energy efficiency gap [1].

This work proposes a project prioritisation tool to close this gap as part of a decision support framework. The proposed framework is aimed at ensuring top management are presented with all the necessary, un-biased characteristics and performance trends, from any site within an organisation, coupled with key performance indicators on the proposed energy performance improvement projects and their associated impact on the organisation.

The prioritisation tool is a hybrid multi-criteria decision method (MCDM) that combines different decision-making methodologies: Analytical Hierarchy Process (AHP), Fuzzy Logic (FL) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In this MCDM, the novelty lies on how the organisation's priorities are translated into criteria weights (i.e. technical, environmental, financial and social) via qualitative assessment by top management.

2 Literature Review

2.1 Decision making in companies

Energy related projects are rarely seen as a priority in manufacturing firms [2], leading to lack of top management involvement, competition for funding with other investments considered as "more important", limited financial resources and unstructured decision making processes [3]. Understanding of the investment decision processes plays a definitive role in the execution of energy projects. Such processes are composed by a sequential and dynamic set of decision events which are not always linked to financial evaluations and depend on diverse context factors that vary from firm to firm. The approval or refusal of proposals is, therefore, influenced by investment categorisation, size, culture and complexity of the organisation [4] [5]. Furthermore, internal and external cultural factors also shape the decision-making processes [6].

Since "profitability plays an important but not decisive role in investment decision-making" [12], strategic alignment of energy projects requires not only attractive financial figures, but also awareness on the connection of energy investments with the organisation´s core business activities. Such awareness presents top managers with compelling, informed business cases [3].

In organisations, energy-related decision-making process begins “once the need for an investment in energy efficiency is identified” [4]. It finishes either with a refusal decision for the investment proposals or with implementation of the measure designed to address the initial need. The evaluation and choice of solutions to address the identified need corresponds to the prioritisation of energy improvement investments required by ISO-50001 [7]. Companies without a specific category for energy investments may create an unbalanced competition between them and other investments directly linked with the firm’s core business. This may lead to negative decision-making outcomes for energy investments not considered strategic [3].

An approach to present top-management with business case supported by a structured, unbiased and informed decision-making framework is needed.

2.2 Multi-criteria decision making for energy projects

Multi-criteria decision methods (MCDM) are techniques that aim at facilitating a rational ranking of alternatives to select the best. MCDM are especially advantageous when using conflicting criteria, as for example, capital cost of energy generation technologies versus their contribution to reduce CO_2 emissions in a manufacturing site.

Large industrial organisations are expected to support a continuous improvement of energy performance to advance the organisation´s sustainability record. The energy management system should employ a holistic approach, aligned to sustainability criteria, to prioritise energy projects. MCDM developed in the field of sustainable energy provide a suitable reference.

The use of sustainability criteria and MCDM to rank energy projects was covered in detail by Wang [8]. Wang’s work identified financial, environmental, social and technical criteria as the preferred set for ranking energy projects. These findings align with the standard triple bottom line (TBL) approach of sustainability assessments (economic, environment, society) [9] complementing it with the technical side of the energy project if needed. Table 1 contains a list of criteria that are frequently used in sustainable energy oriented MCDM.

Table 1. List of evaluation criteria

Criteria	**Sub-Criteria**
Economical	Investment cost – CAPEX
	Payback period (Simply / discounted)
	Annual O&M cost - OPEX
	Equivalent annual cost
	Net present value-NPV
	Internal rate of return - IRR
	Fuel Cost or Electricity cost
	Fuel availability, Service life
Environment	NOx emissions, CO emissions
	CO_2 emissions, SO_2 emissions
	Particles emissions
	Renewable energy fraction
	Volatile hydrocarbons emissions
	Land use, Noise
Social	Social (stakeholders) acceptability
	Job creation, Future suitability
	Effect for energy security
	Benefited communities/ persons
	Safety, Safeguards
Technical	Efficiency, Exergy efficiency
	Automation grade
	Primary energy ratio
	Operability, Reliability
	Technology maturity
	Technology innovation

With regard to the techniques used in energy and sustainability decision-making, Analytical Hierarchy Process (AHP) is the preferred method [10]. AHP is based on disaggregation of a problem into several levels to construct a hierarchy that eases problem solving (see Figure 4**Napaka! Vira sklicevanja ni bilo mogoče najti.**). When applied to sustainability problems, an AHP model with two levels fits the TBL approach. The first level includes the environmental, economic and social criteria. The second level sub-criteria are those included in Table 1.

By combining AHP with other techniques such as TOPSIS and FL, the resulting hybrid-MCDM are appropriate for use in complex multi-criteria assessments involving qualitative criteria, human judgments and uncertainty [11], [12].

TOPSIS is a decision-making technique broadly used due to its simplicity and easy programmable computation process [11]. It is based on the concept that the best alternative shall be the closest to a positive ideal solution, and the farthest to a negative ideal solution [8], [13].

Fuzzy Logic is a theory that supports MCDM in dealing with human uncertainty of decision-makers. This theory facilitates MCDM to use qualitative criteria, for which performance is to be given in linguistic terms rather than numbers (i.e. low or high performance). It also facilitates the estimation of criteria weights, especially when combined with AHP [11]. FL translates linguistic evaluations into numerical figures [14].

3 Methodology

3.1 Decision Support Framework

An organisation's energy strategy should define the targets, roadmap and enablers required to meet the long-term objectives committed to by an energy policy. Meeting the targets requires investment. To ensure optimal investment a 'Decision Support Framework' (DSF) is needed to allow top management unbiased visibility to all potential Energy Efficiency Measures (EEM) from any site [15].

A minimal DSF dataset requires information from both site and corporate level. Site level data (top-row Figure 3) is tactical in nature and includes the proposed energy performance measure parameters (i.e. 1MW solar) and site energy performance metrics (i.e. energy consumption performance history and energy management maturity assessment). The corporate level data (bottom-row Figure 3) is strategic in nature and includes the preferred financial funding mechanism (i.e. own capital vs. Power Purchase Agreements –PPA) and the critical output from a project prioritisation tool.

		DSF	
Site	Current Performance Parameters		Proposal Parameters
Corporate	Investment Model		Prioritisation process output

Figure 3. DSF - Minimal Dataset

The DSF presents a robust overview of all proposed energy projects and their respective impact at a site and organisation levels. Through this presentation of energy opportunities to the executive leadership, informed decision-making may take place promoting increased funding for energy efficient projects across the organisation.

The prioritisation process, as described in next section, is supported by a multi-criteria decision making method (MCDM).

3.2 Multi-criteria decision methods

The proposed MCDM is a hybrid approach that combines Fuzzy Logic, AHP and TOPSIS. It is based on previous MCDM [11], [12] and has the following general characteristics:

- An AHP structure with two levels. Economic, environmental, social and technical criteria on the 1st level. 14 sub-criteria on the 2nd level.
- Economic and environmental criteria composed by quantitative sub-criteria.
- Social and technical criteria composed by qualitative sub-criteria.
- A criteria weighing method based on AHP linguistic pair-wise comparisons, FL and extent analysis [16].
- TOPSIS and FL to establish the best solution.

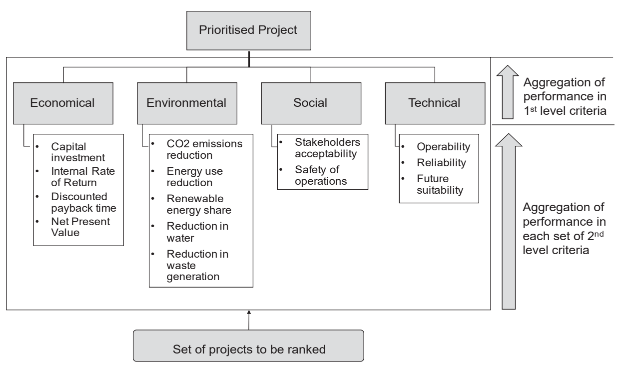

Figure 4. AHP structure and sets of criteria

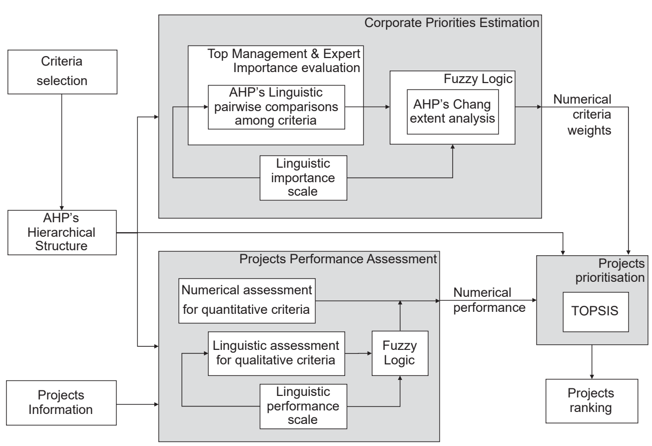

Figure 5. MCDM flowchart

The flowchart presented in Figure 5 describes how the MCDM produces a ranking of energy projects. Qualitative performance assessments are based on subjective opinions about characteristics of energy projects and the technologies involved. Evaluators are provided with the following linguistic performance scale: very low, low, medium, high, very high. The evaluations are then translated into numerical assessments using FL for triangular fuzzy sets (TFN), see Figure 6.

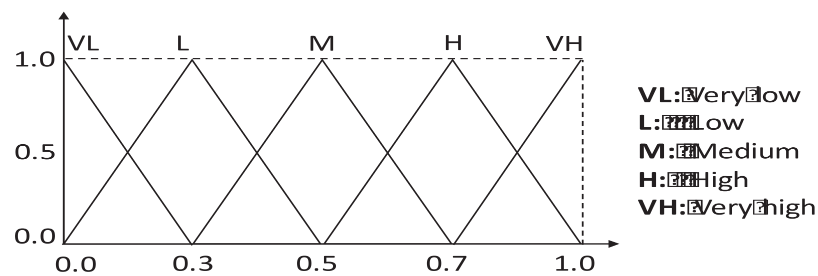

Figure 6. Linguistic performance scale and associated TFN sets [11], [12]

Criteria weights estimation is carried out by AHP pairwise comparisons. This step requires to elucidate the n's priorities when appraising energy projects. As indicated in Figure 5, opinions from the organisation's top managers and experts are used to understand those priorities and translate them into criteria weights. Nonetheless, inherent vagueness is expected in this process. To deal with that uncertainty, the novel MCDM proposed in this research work, requires managers and experts to complete two tasks. First, to judge whether criteria X (i.e. environmental) is more important than criteria Y (i.e. economical) within their organisation. And second, to use a linguistic importance scale to grade the relative importance of the more important criteria over the another (i.e. strongly more important). The linguistic importance scale is provided in Figure 7.

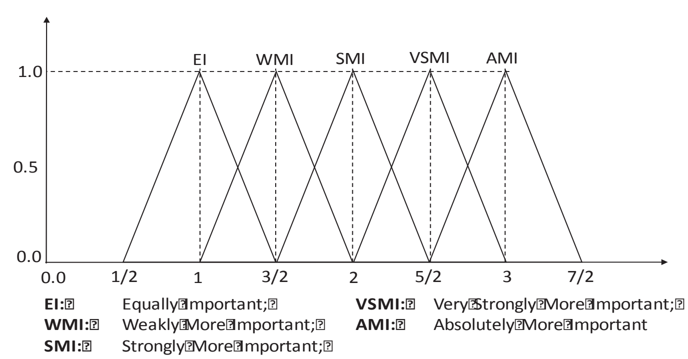

Figure 7. Linguistic importance scale and associated TFN sets [14].

Estimation of the numerical criteria weights is carried out using Chang's Extent Analysis for fuzzy-AHP [5] and the TFN shown in Figure 7.

Final project prioritisation is carried out by the TOPSIS component of the MCDM. It employs the numerical performances of all projects and aggregates them in accordance with the AHP structure and criteria weights. TOPSIS ranks the set of projects based on their geometric distances from the Positive Ideal Solution and the Negative Ideal Solution of the decision-making problem. The MCDM assigns a score of 100% to the top ranked project, because it is the closest project to the ideal solution. The rest of the projects are assigned proportional scores depending on their closeness to the best project. For instance, the score for the bottom ranked project is 0%.

4 Case Study

As part of the development and deployment of a global energy management system [15], the DSF and associated MCDM described in Section 3 have been implemented to assist the investment decision for five energy projects in five different manufacturing sites in Boston Scientific Corporation (BSC). BSC is a non-energy intensive multi-national manufacturing corporation. For BSC, the DSF serves two mutually exclusive target audiences:

- Clear presentation of energy opportunities to the executive leadership;
- Normalized benchmark performance for the site energy manager.

4.1 MCDM application

Criteria weighing: The criteria weights were estimated using FL to transform the linguistic pairwise comparisons carried out by the appropriate top managers and experts in each discipline within the organisation. The estimated weights for first and second level criteria are reported in Table 2.

Table 2. Criteria weights

Description	Weight %	Description	Weight %
Economic	31	Initial Capital Investment	18
		Net Present Value	47
		Internal Return Ratio	18
		Discounted Payback Time	18
Environmental	34	CO2 Emissions Reduction	29
		Energy Consumption Reduction	29
		Renewable Energy Share	26
		Water Consumption Reduction	1
		Waste Generation Reduction	14
Social	9	Safety of Operation	68
		Stakeholder's Acceptability	32
Technical	26	Operability	34
		Reliability	56
		Future Suitability	10

Table 2 indicates that environmental performance is the priority when ranking energy projects at BSC. The economic criteria are the second priority, followed closely by the technical criteria.

Projects: The MCDM was applied to prioritise five energy investment opportunities BSC. The set of projects comprises a Tri-generation System (P1) for Site 1; a new Combined Heat & Power plant (P2) for Site 2; an Ice Storage System (P3) for Site 3; a Chillers' Upgrade project (P4) for Site 4; and a Solar PV System (P5) for Site 5.

The evaluation matrix: Information for the five projects per the criteria listed in Table 2 is presented in the evaluation matrix Table 3. Performances for quantitative and qualitative criteria are numerically and linguistically expressed respectively.

Project prioritisation: The prioritisation outcome is shown in Table 4. It depicts the project 'P5' as the top ranked, followed by project 'P2', which offers only half the rating than 'P5'. The output of the MCDM provides an unbiased ranking for the available investment opportunities based on the priorities of the organisation as defined by the criteria weighting. This score is the input into the DSF (Figure 1).

Table 3. Decision-making matrix

First Level Criteria	**Second Level Criteria**		**P1**	**P2**	**P3**	**P4**	**P5**
	Attribute	**Description**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**
Economic	Cost	Initial Capital Investment ($)	$2,575,000	$1,346,000	$1,250,000	$800,000	$0
	Benefit	Net Present Value (S)	$841,000	$1,900,000	$609,627	$996,000	$900,000
	Benefit	Internal Return Ratio (%)	19	45	23	40.0	100
	Cost	Discounted Payback Time (yr.)	3.9	2.1	3.6	2.7	0.0
Environmental	Benefit	CO_2 Emissions Reduction (%)	1.9	1.5	0.0	0.5	0.6
	Benefit	Energy Consumption Reduction (%)	1.9	1.3	0.6	0.4	0.2
	Benefit	Renewable Energy Share Increment (%)	0.0	0.0	0.0	0.0	37.0
	Benefit	Water Consumption Reduction (%)	0.0	0.0	0.0	0.0	0.0
	Benefit	Waste Generation Reduction (%)	0.0	0.0	0.0	0.0	0.0
Social	Benefit	Safety of Operation	High	High	High	High	Very High
	Benefit	Stakeholder's Acceptability	Very High	Very High	Medium	High	Very High
Technical	Benefit	Operability	High	High	High	High	Very High
	Benefit	Reliability	High	High	High	High	High
	Benefit	Future Suitability	Medium	Medium	Very High	Medium	Very High

4.2 DSF results

The DSF application results is shown in Table 4.

The proposed DSF approach and its implementation at BSC resulted in four projects being funded in 2016. This is attributable, among other elements, to the improved decision-making process for energy projects enabled by the DSF.

Table 4. DSF dataset[2]

Project	Investment model	MCDM Output	Current Performance		Proposal Investment ($)
			Energy Indicator	Maturity indicator	
P1	Own capital	3 (30%)	134	2.4	$2,575,000
P2	Own capital	2 (50%)	128	2.2	$1,346,000
P3	Own capital	4 (20%)	97	2.2	$1,250,000
P4	Own capital	5 (0%)	78	2.1	$800,000
P5	PPA	1 (100%)	78	2.1	$0

5 Conclusions

The aim of the DSF is to present top management with an easy to understand yet comprehensive data-set of necessary, unbiased, information from proposed energy conservation measures to aid in the decision-making process. From the global energy manager perspective, the DSF is a condensed, repeatable, and effective template to request approval for funding, while for the executive leadership, it constitutes an understandable, fact based approach to reach informed decisions enabling optimal investment across the organisation.

The role of the DSF is not to eradicate the need for expert knowledge in project selection. It is important to note that the MCDM score does not necessary determine the order for funding. For example, the decision may conclude that the strategic need to improve the performance of one site out-weights the importance placed on the MCDM output for each individual project. In fact, the driver for capital investment may be to bring all sites to an acceptable level of performance and subsequently generate a list of projects to be implemented. This enables energy to become an asset that is maintained and invested in to ensure optimum running costs across the network. With a site only approach this is non-existent.

The outputs of the MCDM are twofold. On the one hand, it elucidates the relative priorities given by the organisation to the environmental, economic, social and technical dimensions of energy improvement projects. On the other hand, it provides an objective prioritisation guide for resource allocation. Regarding the corporation's priorities, as per results shown in Table 2, this reveals that a project's contribution to improve the environmental footprint and business continuity have higher priority than financial benefits within this organisation. This outcome is aligned with results from empirical works on investment decisions for energy efficiency projects.

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Notes

1 As suggested by previous literature, a company can be considered as non-energy intensive if its energy costs are less than 2% of its turnover or are less than 5% of its production costs [6], [17].
2 The energy and maturity indicators are outside the scope of this paper, the interested reader is referred to [15].

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