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Hybrid multiple criteria decision-making methods: a review of applications for sustainability issues

Edmundas Kazimieras Zavadskas, Kannan Govindan, Jurgita Antucheviciene and Zenonas Turskis

Department of Construction Technology and Management, Vilnius Gediminas Technical University, Vilnius, Lithuania; Center for Sustainable Engineering Operations Management, Department of Technology and Innovation, University of Southern Denmark, Odense, Denmark

ABSTRACT

Formal decision-making methods can be used to help improve the overall sustainability of industries and organisations. Recently, there has been a great proliferation of works aggregating sustainability criteria by using diverse multiple criteria decision-making (MCDM) techniques. A number of review papers summarising these techniques have been published. During the past few years, new approaches for hybrid MCDM (HMCDM) methods have been developed, but they have not yet been completely reviewed. This article aims to fill this gap and to summarise publications related to the application of HMCDM. The current study is limited solely to papers available in the Thomson Reuters Web of Science Core Collection database. The main findings report that HMCDM methods have been increasingly applied for supporting decisions in different domains of sustainability. The most frequently used methods emphasise the advantages of hybrid approaches over individual methods, and we conclude that they can assist decision-makers in handling information such as stakeholders’ preferences, interconnected or contradictory criteria, and uncertain environments. The main contribution of this work is identifying hybrid approaches as improvements for decision-making related to sustainability issues, while also promoting future application of the approaches.

1. Introduction

The concept of sustainability has become one of the most important objectives in many activities because of greater concerns for environmental protection and social responsibility. In modern economies, financial aspirations must be balanced with social and environmental interests. To address potentially contradictory concerns and to achieve good compromise solutions, it is helpful to evaluate sustainable production and management strategies by applying formal decision-making methods.
Multiple criteria decision-making (MCDM) models have grown as a part of operation research, combining mathematical and computational tools to provide a subjective evaluation of performance criteria by decision-makers (Mardani, Jusoh, & Zavadskas, 2015).

The first references that address multiple criteria mathematical methods to support decisions emerged as far back as the eighteenth century (De Condorcet, 1785; Franklin, 1772). In the nineteenth century, the works of Edgeworth (1881) and Pareto (1896) made significant contributions. The first decision-making axioms were presented in the twentieth century by Ramsey (1931). Soon, Von Neumann and Morgenstern (1944) announced the Theory of Games and Economic Behavior. Ten scientists were awarded the Nobel Prize in economics for the creation of a decision-making theoretical framework (Arrow, 1951; Danzig, 1948; Debreu, 1959; Frisch, 1961; Kantorovich, 1960; Koopmans, 1951; Nash, 1950; Samuelson, 1938; Sen, 1970; Simon, 1955). In the same period, a number of other important works related to decision-making theory were published (Edwards, 1954; Fishburn, 1970; Gass & Saaty, 1955; Luce & Raiffa, 1957; Roy, 1968; Zadeh, 1965; Zelany, 1974).

The title MCDM was first suggested in 1975 (Zeleny, 1975). Four years later, this new notion was explained by Zionts (1979) and gained universal recognition. MCDM methods can be classified into discrete multiple attribute decision-making (MADM) methods (Hwang & Yoon, 1981) and continuous multiple objective decision-making (MODM) methods (Hwang & Masud, 1979). The theory of MCDM was summarised by the author of the term (Zeleny, 1982).

Since 1990, MCDM methods have rapidly developed and have been applied to support strategic decisions in different areas. Developments and applications of MCDM methods have been summarised by a number of authors (Roy, 1996; Saaty, 1996; Zavadskas, Peldschus, & Kaklauskas, 1994; Brauers, 2004; Figueira, Greco, & Ehrgott, 2005; Triantaphyllou, 2010; Zopounidis & Pardalos, 2010; Köksalan, Wallenius, & Zionts, 2011; Behzadian, Kazemzadeh, Albadi, and Aghdasi (2010); Govindan and Jepsen (2016). MADM and MODM methods were more recently summarised by Tzeng and Huang (2011, 2013).

Many studies have employed MCDM tools to solve problems in engineering, science, technology, economics, and other fields (Mardani et al., 2015). But the presence of so many MCDM approaches bewilders users, resulting in the difficulty of selecting one appropriate method (Saaty & Ergu, 2015). Zavadskas and Turskis (2011) reviewed numerous applications of MCDM methods in economics, and Liou and Tzeng (2012) published a response to the previous publication. That 2012 publication was followed by a paper reviewing Tzeng’s contributions (Liou, 2013). A special issue on MCDM for engineering was published (Wiecek, Matthiaeheggert, Fadel, & Ruifigueira, 2008). Applications in a separate area of civil engineering as building and construction were presented (Jato-Espino, Castillo-Lopez, Rodriguez-Hernandez, & Canteras-Jordana, 2014; Zavadskas, Lias, & Turskis, 2008). Reviews devoted to decision-making in related areas as infrastructure management (Kabir, Sadiq, & Tesfamariam, 2014), asset management (Gay & Sinha, 2013), E-learning (Zare et al., 2016) were published. Zavadskas, Turskis, and Kildienė (2014) summarised reviews (review papers and books) on a topic of MCDM. Systematically classified information on methods and applications, covering 2000–2014 and involving nearly 400 papers grouped in 15 fields, can be observed in the recent review (Mardani et al., 2015a). It is worth mentioning that energy, environment, and sustainability were ranked as the areas that have the most
frequently applied diverse decision-making techniques and approaches, based on multiple criteria assessment (Mardani et al., 2015).

Sustainability is a natural subject of MCDM, because, by itself, it includes three sub-sets of criteria: economics, environmental, and social aspects (Antucheviciene, Kala, Marzouk, & Vaidogas, 2015). When analysing sustainable industries, a fourth sub-set of criteria – involving engineering and technological dimensions – is also important. A review of methodologies applied for assessing and selecting technological alternatives from a sustainability perspective was presented by Ibáñez-Forés, Bovea, and Pérez-Belis (2014). The assessment process involves several stages of choosing criteria, ranking or weighting them, followed by comparing and selecting the alternatives. There are a lot of methods which have been created for the different stages of decision-making for sustainable technology selections. According to Ibáñez-Forés et al. (2014), criteria can be compared directly without weighting, with equal weighting, or by applying different methods of subjective and objective weighting. Direct ranking, outranking, multi-attribute utility theories, multi-objective programming, elementary aggregation methods, or complex and non-classical aggregation methods can be applied for selecting the best alternative.

One of the more innovative themes in sustainable production is related to using materials of low embodied energy, renewable resources, and energy efficient applications. An overview of applications of MCDM approaches for sustainable and renewable energy problems was produced (Mardani, Jusoh, Zavadskas, Cavallaro, & Khalifah, 2015). The overview classifies the approaches into two categories: classical MCDM and non-classical, i.e., fuzzy methods (FMCDM).

Supplier selection is another key task for developing sustainable supply chains and for production management on the whole. The vital issue of using MCDM approaches for green supplier evaluation and selection was analysed by Govindan, Rajendran, Sarkis, and Murugesan (2015). In that paper, the decision-making methodology base is classified into two main categories: individual approach and integrated approach.

According to Govindan et al. (2015), many of the latest approaches integrate fuzzy logic. The extended methods based on fuzzy logic receive more and more attention. 2015 marked the 50th anniversary of the introduction of the Fuzzy Sets Theory by Zadeh (1965), and special anniversary journal issues were published (Herrera-Viedma, 2015; Yager, 2015). Mardani et al. (2015) published a comprehensive review on extended MCDM, namely on developments and numerous applications of FMCDM. The review of Antucheviciene et al. (2015) examines applications of decision-making methods for dealing with uncertainties in engineering problems applying extended methods by means of fuzzy logic and probabilistic modelling. Non-classical approaches, called complex (Ibáñez-Forés et al., 2014), or integrated (Govindan et al., 2015; Ho, Xu, & Dey, 2010), or hybrid (Shyur & Shih, 2006; Tzeng, Chiang, & Li, 2007) have not been reviewed completely so far. Accordingly, the current paper aims at filling the gap and summarising publications related to developments and especially to applications of hybrid MCDM (HMCMD) methods, including those for supporting overall sustainability and for promoting their usage in modern decision-making. Because HMCMD approaches represent a relatively new and progressive trend, their abilities to join different techniques can assist decision-makers in handling miscellaneous information, involving stakeholders’ preferences, interconnected or contradicting criteria, and uncertain environments.
2. Research methods and scope

The literature related to HMCDM models, abbreviated as HMCDM, has been reviewed comprehensively on the basis of papers referred in Thomson Reuters Web of Science academic database.

Mesghouni et al. (1999) can be considered the first reference to a hybrid approach in decision-making, because it examined the coupling of three approaches, given as a hybrid approach, to solve a scheduling problem: genetic algorithms (GAs), constraint logic programming (CLP), and MCDM (Mesghouni et al., 1999). The term ‘HMCDM’ was firstly applied by Shyur and Shih (2006) for the use of the MCDM approach, which incorporated the technique of an analytic network process (ANP) and the technique for order performance by similarity to idea solution (TOPSIS). Tzeng et al. (2007) presented a novel HMCDM model based on factor analysis and DEMATEL. Tzeng authored and co-authored many papers that popularised the term ‘Hybrid MCDM’ in the scientific community. The acronym ‘HMCDM’, as used in the current paper, was presented by Liao, Wu, Huang, Kao, and Lee (2014) for the first time. The acronym as a keyword is presented in a paper co-authored by Tzeng (Pourahmad et al., 2015). Note, however, that the acronym ‘HMCDM’ is applied less frequently than the phrase ‘Hybrid MCDM’ to identify the analysed methods in publications. Consequently, ‘Hybrid MCDM’ is applied as the main keyword in the current research.

HMCDM involves four groups of decision-making methods or their combinations with other methods. Figure 1 depicts how the MCDM methods may be combined with methods to calculate the relative significance of criteria, as well as fuzzy sets or grey numbers.

Several shortcomings of usual classical MCDM methods can be solved by using the proposed variety of hybrid methods as follows:

1. Selecting an appropriate method is a continuous challenge in every situation that requires a decision. Different MCDM methods sometimes yield different rankings of alternatives. No one method can be considered best either for a general or for a particular problem (Saaty & Ergu, 2015). Accordingly, it is recommended to use more than one MCDM method and to integrate results for final decision-making.

![Figure 1](image-url)  
*Figure 1. Composition of hybrid MCDM. Source: Created by the authors.*
Ranking order and the final decision can vary significantly depending on the importance of each criterion in the analysed problem. There are studies available without weighting when the same importance is assigned to all criteria considered (Ibáñez-Forés et al., 2014). The hybrid approach suggests solving two tasks simultaneously, such as determining criteria weights and values and integrating them to the multi attribute utility function value. Moreover, integrating criteria weights, determined by using different objective and subjective weighting methods, helps to reflect stakeholders’ preferences more carefully.

The decision-making models should be as close as possible to real-life problems. Fuzziness in the decision-making process often stems from a context of managerial uncertainty, when ambiguities and difficulties make reaching a proper decision difficult. Accordingly, integrating MCDM with fuzzy sets or grey numbers is preferred. Fuzzy logic could help to overcome uncertainties that arise from human qualitative judgements and incomplete preference relationships (Govindan et al., 2015).

Some other techniques can also be employed to add more justification in the problem formulation. Because of sustainability assessments’ lack of overall acknowledged metrics (Ingwersen et al., 2014), quantitative and qualitative methods can be applied for generalising information, selecting sustainability assessment indicators, and deriving evaluation criteria for further multiple criteria analysis.

Following the suggested scheme outlined in Figure 2, the first available publications in the area are reviewed.

The research solely reviews papers referred in the Web of Science, Core Collection Database, and the search was made in the Online Database on 21 October 2015. In the initial overview, we searched for ‘MCDM’ and ‘Hybrid MCDM’ keywords in all document types in the Web of Science Database. Distribution of documents by publication years and countries, and by research areas was overviewed. For the detailed analysis of decision-making methods used in developing hybrid approaches and application areas of the approaches, ‘Hybrid MCDM’ was used as a search keyword, and only journal papers (articles and reviews) were searched.

The research presents the results of analysis as follows:

1. How are applications of the methods distributed, both by a period of publishing and by a country?

Are HMCDM methods recognised as a useful tool to support evaluation and selection processes related to sustainability issues? Is their application increasing? Are these methods applied globally or do some regions (or scientific schools) utilise the methods differently? What are the prospects of their future development?

2. Which MCDM methods are used the most frequently in HMCDM?

Because no MCDM method may be considered the best (Saaty & Ergu, 2015) and each method is individually selected for a particular problem, it is worthwhile to explore which methods are used in hybrid approaches related to sustainable decisions. What are the most applicable types of aggregation of the methods? What methods are recommended to be applied based on state-of-the-art surveys in different research areas related to sustainability?
(3) In what research areas are HMCDM fruitfully applied?

As decision-making in sustainability is a very broad subject, involving products, technologies, service assessments, and strategy/scenario selections, the review intends firstly to sort out the applications by research areas as classified in the Web of Science Database. Secondly, we then seek to present more detail by research domains to identify which issues are better served by a hybrid approach over an individual method. Which applications of hybrid methods are increasing in different domains? Have new fields of application been discovered? What are the most adequate types of aggregation of the methods for different domains?

3. Findings of the research

An overview of papers is presented, including information on publication years, countries, and applied MCDM methods. Then, a detailed survey of articles by research areas and research domains related to sustainability is made. Results of the research are summarised in several tables and figures.
3.1. Distribution based on publication years and countries

There are 2450 publications on the topic of MCDM cited in the Web of Science Core Collection (21 October 2015), covering all the document types, including articles (1749), reviews, proceedings papers, and other documents (Table 1).

From 2450 publications, 251 (10.24%) are devoted to HMCDM. Scholarly articles on HMCDM cover 11.26% of the whole number of articles on the topic of MCDM, respectively (Table 1).

The extent of research in the area has increased rapidly over the last 10 years, as can be observed in Figures 3–4. The number of publications on HMCDM increased from 1–2 papers per year from 1999–2006 up to 45 journal articles in 2015. Eighty-four per cent of articles in the area have been published during the last five years (2011–2015). Articles from the last two years (2014–2015) comprise 50%, respectively, of the total publication volume.

MCDM application by countries has also been analysed. Information on distribution of papers by country of origin is presented in Figure 5.

MCDM methods have been applied by researchers affiliated in 85 countries all over the world. The leaders among countries are: Taiwan (455), China (323), Iran (246), USA (240), Turkey (193), Lithuania (141), and India (141). From 50 to 100 papers were published by researchers from Malaysia (80), Canada (73), Australia (72), England (71), South Korea (70),

Table 1. Publications on the topic of MCDM and HMCDM in the Web of Science database.

| Type of Publications                      | Number of Publications |
|-------------------------------------------|------------------------|
| Publications on MCDM methods              |                        |
| all                                       | 2450                   |
| articles                                  | 1749                   |
| Publications on hybrid MCDM methods       |                        |
| all                                       | 251                    |
| articles                                  | 197                    |

Source: Author's calculation based on the Web of Science database.

Figure 3. Number of publications on the topic of MCDM (total: 2,450). Source: Created by the authors.
Spain (68), and France (52). Figure 5 involves data on countries that have been published more than 10 papers. Also, Ireland published nine papers, eight papers were published by New Zealand and Tunisia authors; seven – Romania; six – Indonesia and Saudi Arabia; five – Jordan and Norway. The input of the remaining identified countries is 1–4 papers.

A little different distribution is observed when analysing HMCDM developments and applications by country of origin (Figure 6). HMCDM methods have been applied...
by researchers affiliated in 34 countries all over the world. The leader is the same, i.e., Taiwan (103). The next comes Iran (38), Turkey (26), China (25), Lithuania (22), India (17), Malaysia (16), and the US (13). Other countries showed only a few attempts in a field of HMCDM. Four papers have been published by researchers from Australia, Ireland, Japan, and South Korea (four). France published three papers, Canada, Denmark, England, Finland, Germany and Spain – two. The remaining 15 countries have presented one paper on HMCDM applications.

What are the reasons Taiwan emerges as the leader in the number of publications authored? Taiwan’s dominant ranking is primarily due to the work of the famous Taiwanese scientist, Gwo-Hshiung Tzeng, who is the author of early publications on HMCDM methods. He popularised the analytic approach in the scientific community; he authored and co-authored a lot of papers, and his works are highly cited. His paper presenting a novel HMCDM model based on factor analysis and DEMATEL (Tzeng et al., 2007) was cited 243 times which placed it in the top 1% of the most highly cited works in the academic field of engineering. Forty-seven of his papers on a subject of HMCDM are refereed in the WoS database, and those publications represent 42% of all Taiwanese papers on the subject. Tzeng’s scientific school inspired other scientists to use his methods in their own research, and these methods eventually spread to other countries due to international scientific collaboration.

### 3.2. Distribution based on applied MCDM methods

When developing HMCDM methods, modular MCDM or extended MCDM methods have been used (Figure 7), and the most frequently used methods are ANP, DEMATEL TOPSIS, AHP, and VIKOR. Of the top five most commonly cited methods, VIKOR receives 57 applications (48 in articles) and ANP, the highest, receives 110 in all documents (93 in
After the mentioned well-known methods, two newly developed approaches follow: COPRAS (with 14 citations, 13 in articles) and SWARA (10 citations, nine in articles). The other methods were used in developments fewer than 10 times.

### 3.3. Distribution based on research areas

Figure 8 presents information on the application areas of HMCDM. The records are ranked by Research Areas as presented in the Web of Science database.
It is observed that the methods have been applied in 32 areas, but the majority of research is found in seven areas, including Computer Science (117), Engineering (107), Operational Research & Management Science (73), Business Economics (40), Mathematics (24), Energy Fuels (13), and Environmental Sciences Ecology (10). The figure presents Research Areas involving two or more papers (all document types in the Web of Science database).

Next, our review identifies data only (‘article’ and ‘review’ document types in the Web of Science database), and we find 197 publications for 21 October 2015).

The top 10 application areas of the analysed HMCDM papers from the Web of Science database, compared with the application areas of other papers on MCDM, are presented in Table 2.

After analysing every selected paper by topic and decision-making methods applied, the papers were grouped into four groups by area of research (Figure 9). A majority of these papers is devoted to, or involve elements of, sustainability/sustainable development.

The problems solved and MCDM methods applied in HMCDM are described in Tables 3–6; the tables follow the classifications identified in Figure 9 and begin with supply

### Table 2: Research areas of papers.

| Research Area                           | HMCDM number of articles / per cent | MCDM number of articles / per cent |
|-----------------------------------------|-------------------------------------|------------------------------------|
| Computer Science                        | 84 / 42.64                          | 643 / 35.72                        |
| Engineering                             | 82 / 41.62                          | 645 / 35.83                        |
| Operations Res. Mgt. Sc.                | 67 / 34.01                          | 496 / 27.56                        |
| Business Economics                      | 34 / 17.26                          | 329 / 18.28                        |
| Mathematics                             | 20 / 10.15                          | 193 / 10.72                        |
| Energy Fuels                            | 13 / 6.56                           | 63 / 3.50                          |
| Environmental Sciences Ecology          | 9 / 4.57                            | 141 / 7.83                         |
| Automation Control Systems              | 7 / 3.55                            | 71 / 3.94                          |
| Mechanics                               | 7 / 3.55                            | 34 / 1.89                          |
| Science Technology Other Topics         | 7 / 3.55                            | 35 / 1.94                          |

*Papers can be simultaneously assigned to several Research Areas in Web of Science database; therefore the sum of per cent exceeds 100.

Source: Author’s calculation based on the Web of Science database.

![Figure 9. Research Areas of selected hybrid MCDM methods. Source: Created by the authors.](image-url)
| The Problem Solved                                                                 | Method*                                             | Publication                  |
|----------------------------------------------------------------------------------|-----------------------------------------------------|-----------------------------|
| Dealing with sustainability issues                                                |                                                    |                             |
| Evaluation of green manufacturing practices                                      | DANP, PROMETHEE, VIKOR, TFNs                        | Govindan et al. (2015)      |
| Evaluation of green supply chain management practices by measuring the uncertainty of activities and solving the MCDM problem | FAD, Fuzzy AHP, PROMETHEE, INRM                    | Rostamzadeh et al. (2015a) |
| Simulation of drivers for better adoption of green manufacturing                 | Fuzzy AHP, MODM, Fuzzy DEMATEL                      | Kannan et al. (2015)        |
| Improving the performance of green suppliers in crystal display industry         | ELECTRE, VIKOR, Grey numbers                        | Govindan et al. (2015)      |
| Selection of sustainable supplier lot-sizing order                               | FDM, DEMATEL, DANP, VIKOR                          | Tsui et al. (2015)          |
| Decision-making under uncertainty in green supply chain problems                 | AHP, ANP, DEA, ELECTRE, PROMETHEE, TOPSIS, VIKOR   | Azadnia et al. (2015)       |
| Modelling green supplier selection                                               |                                                    | Wu et al. (2015)            |
| Supply chain environmental performance evaluation                                 |                                                    | Kuo et al. (2015)           |
| Low carbon supplier selection in hotel industry                                   |                                                    | Chithambaranathan et al. (2015) |
| Selecting green supplier of thermal power equipment                              |                                                    | Zhao and Guo (2014)         |
| City logistics concept selection                                                 |                                                    | Tadić et al. (2014)         |
| Review of literature on supplier selection                                       |                                                    | Chai et al. (2013)          |
| Using a novel hybrid MCDM approach to evaluate green suppliers                   |                                                    | Büyükközkan and Čifçi (2012) |
| Selecting the vendor selection for recycled material                             |                                                    | Hsu et al. (2012)           |
| Other topics                                                                     |                                                    |                             |
| Evaluation outsourcing provider with an example in a telecommunication company   | DEMATEL, fuzzy ANP                                 | Uygun et al. (2015a)        |
| Supplier selection                                                              |                                                    |                             |
| Material routing optimization in supply chain                                     | ANP, Intuitionistic fuzzy TOPSIS                    | Rouyendegh (2015)           |
| Evaluating different strategies in supply                                        | Fuzzy AHP, TOPSIS, GA                              | Rostamzadeh et al. (2015b)  |
| Supplier selection                                                              | SWARA-WASPAS, game theory                          | Hashemkhani Zolfani et al. (2015) |
| Supplier evaluation and improvement                                             | Semi-fuzzy SVD                                      | Guo et al. (2014)           |
| Third-party logistics selection problem                                         | ANP, DEMATEL, DANP, Fuzzy integral                 | Liu et al. (2014b)          |
| Human resources performance evaluation                                           | FST, AHP, ANP, TOPSIS, ISM, VIKOR, DEMATEL, QFD, ELECTRE, Utility theory | Augezzoul (2014)            |
| Personnel selection                                                              | ANP                                                | Gürbüz and Albayrak (2014)  |
| Supplier selection with interdependent criteria                                  | Fuzzy DEMATEL, Fuzzy ANP                           | Kabak (2013)                |
| Model for supplier selection                                                     | AHP, TOPSIS                                        | Kasirian and Yusuff (2013)  |
| Supplier selection in continuously changing environment                          | Fuzzy Delphi, TOPSIS, ANP                          | Wu et al. (2013)            |
| Selection of an outsourcing provider                                             | SWARA, VIKOR                                       | Alimardani et al. (2013)    |
| Enterprise resource planning                                                     | DEMATEL, DANP, GRA                                 | Hsu et al. (2013)           |
| Logistics tool selection                                                         | DEMATEL, ANP                                       | Tsai et al. (2013)          |
| Personnel selection for teamwork                                                 | DEMATEL, Fuzzy TOPSIS                              | Büyükközkan et al. (2012)   |
|                                                                             | AHP, TOPSIS–G                                      | Hashemkhani Zolfani and Antucheviciene (2012) |
Selecting company supplier AHP, COPRAS–G Zolfani et al. (2012a)
Selection quality control manager in a company AHP, COPRAS–G Hashemkhani Zolfani et al. (2012b)
Creating global intelligent manufacturing and logistics systems DEMATEL, VIKOR, GRA Tzeng and Huang (2012)
Novel method for the best vendor selection ANP, DEMATEL Yang and Tzeng (2011)
An innovative supplier selection MULTIMOORA, MULTIMOORA–2T Balezentis and Balezentis (2011)
A hybrid approach to group decision-making in a fuzzy environment VIKOR, GRA Su (2011)
Selecting an outsourcing provider ANP, DEMATEL, FPP Liou et al. (2011)
Training providers' evaluation AHP, fuzzy TOPSIS, fuzzy PROMETHEE Ignatius et al. (2010)
Personnel selection in manufacturing companies ANP, TOPSIS Dağdeviren (2010)
Selecting outsourcing vendor selection for a semiconductor industry TOPSIS, ANP Lin et al. (2010b)
Strategic vendor selection ANP Shyur and Shih (2006)

DEMATEL-based ANP (ANP); Decision-Making Trial and Evaluation Laboratory (DEMATEL); Visekriterijumska Optimizacija i Kompromisno Resenje (in Serbian), that means Multicriteria Optimization and Compromise Solution (VIKOR); Triangular Fuzzy Numbers (TFNs); Fuzzy Axiomatic Design (FAD); Analytic Hierarchy Process (AHP); Preference Ranking Organisation METHOD for Enrichment of Evaluations (PROMETHEE); Influential Network Relation Map (INRM); Multiple Objective Decision-Making (MODM); Elimination et Choix Traduisant la Réalité, that means Elimination and Choice Expressing Reality (ELECTRE); Fuzzy Delphi Method (FDM); Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Technique for Order of Preference by Similarity to Ideal Solution with grey numbers (TOPSIS–G); Analytic Network Process (ANP); Data Envelopment Analysis (DEA); Genetic Algorithm (GA); Step-wise Weight Assessment Ratio Analysis (SWARA); Weighted Aggregated Sum Product Assessment (WASPAS); Support Vector Domain Description (SVDD); Fuzzy Sets Theory (FST); Interpretive Structural Modelling (ISM); Quality Function Deployment (QFD); Grey Relational Analysis (GRA); Complex Proportional Assessment (COPRAS) and Complex Proportional Assessment with grey numbers (COPRAS–G); Fuzzy Preferences Programming (FPP); Multiobjective Optimisation by Ratio Analysis plus Full Multiplicative Form (MULTIMOORA) and Multiobjective Optimisation by Ratio Analysis plus Full Multiplicative Form based on the interval 2-tuple linguistic variables (MULTIMOORA–2T).

Source: Created by the authors.
| The problem solved                                                                 | Methods** | Authors                                      |
|-----------------------------------------------------------------------------------|-----------|----------------------------------------------|
| **Sustainability issues**                                                          |           |                                              |
| Evaluation benefit of renewable energy in terms of sustainability                  | Entropy, fuzzy GRA                             | Zhao and Guo (2015)                          |
| A review on applications of decision-making methods in problems related to renewable energy systems | ANFIS, fuzzy AHP, fuzzy MCDM                   | Suganthi et al. (2015)                       |
| Evaluating health-care waste treatment technologies                               | DEMATEL, MULTIMOORA, fuzzy sets                | Liu et al. (2015a)                           |
| Financial evaluation of the IT industry                                            | Fuzzy ANP, ISM                                | Chen et al. (2015)                           |
| Determining vehicle telematics systems product or service                          | DEMATEL: FIS, VCC-DRSA                        | Shen and Tseng (2015b)                       |
| Assessing regions priority for implementation of solar projects                    | DEMATEL: ANP, VIKOR                           | Lin (2015)                                   |
| Selecting the best plastic recycling method                                       | SWARA, WASPAS, Delphi                         | Vafaiepour et al. (2014)                     |
| Assessing building energy performance                                             | AHP, TOPSIS                                   | Vinodh et al. (2014)                         |
| Prioritisation of renewable energy sources                                        | Fuzzy ANP                                     | Kabak et al. (2014)                          |
| Efficiently allocating energy resources in the case of high oil prices            | ANP, BOCR                                      | Kabak and Dağdeviren (2014b)                |
| Improving environmentally oriented strategies for green innovation performance     | Fuzzy TOPSIS, MODM                            | Perera et al. (2013)                         |
| Review of methodologies for off-grid electricity supply decisions                 | Fuzzy AHP, DEA                                | Lee et al. (2013)                            |
| Evaluation of intelligent sensors and selecting the most suitable for structural health monitoring of bridges | SWARA, WASPAS                                | Bitalafan et al. (2014)                      |
| Machine tool selection considering interactions of attributes                     | Fuzzy DEMATEL, Fuzzy AHP                      | Yeh et al. (2014)                            |
| Exploring smart phone improvements                                                | Fuzzy ANP, COPRAS–G                           | Nguyen et al. (2014)                         |
| Improving transportation service quality                                           | DEMATEL, ANP, VIKOR                           | Hu et al. (2014)                             |
| Determining the quality grade of gas well-drilling projects                        | DEMATEL, Fuzzy integral, ANP                  | Liou et al. (2014a)                          |
| New product development and selection problem                                      | Fuzzy ANP, DEMATEL, Topsis                   | Chyu and Fang (2014)                         |
| Selection of the best biodiesel blend for IC engines                              | Fuzzy AHP, Fuzzy TOPSIS                       | Saktivel et al. (2013)                       |
| Desalination process selection                                                    | Fuzzy AHP, TOPSIS                             | Ghasssemi and Danesh (2013)                  |
| Selecting the best variant of mechanical ventilation in order to effectively remove pollutants in a case of automobile accidents in tunnels | SWARA, VIKOR                                  | Zolfani et al. (2013b)                       |

**Other topics**

| Urban stormwater construction method selection                                     | Fuzzy AHP, CP                                 | Ebrahimian et al. (2015)                     |
| Machine tool evaluation by applying hybrid methods                                 | AHP, fuzzy COPRAS                             | Nguyen et al. (2015)                         |
| Making decisions in the information and communications technology sector           | 2-tuple linguistic computational model, MCDM  | Cid-López et al. (2015)                      |
| Solving a problem of ship engine troubleshooting                                   | Fuzzy AHP, fuzzy VIKOR                        | Balin et al. (2015)                          |
| Organisational decisions for hospital information system                           | ANP, DEMATEL                                  | Ahmad et al. (2015)                          |
| Analysis of failure mode and effects                                               | Fuzzy AHP; Entropy; fuzzy VIKOR               | Liu et al. (2015b)                           |
| Evaluating critical success factors in construction projects                       | ANP, DEMATEL, GRA                             | Nilashi et al. (2015)                        |
| Assessment of intellectual capital for ITc industry                                | DEMATEL, ANP                                  | Chen and Chen (2015)                         |
| Evaluation of intelligent sensors and selecting the most suitable for structural health monitoring of bridges | SWARA, WASPAS                                 | Bitalafan et al. (2014)                      |
| Identification of critical factors in new product development                      | Fuzzy DEMATEL, Fuzzy AHP                      | Yeh et al. (2014)                            |
| Machine tool selection considering interactions of attributes                      | Fuzzy ANP, COPRAS–G                           | Nguyen et al. (2014)                         |
| Exploring smart phone improvements                                                 | DEMATEL, ANP, VIKOR                           | Hu et al. (2014)                             |
| Improving transportation service quality                                           | DEMATEL, Fuzzy integral, ANP                  | Liou et al. (2014a)                          |
| Determining the quality grade of gas well-drilling projects                        | Fuzzy ANP, DEMATEL, Topsis                   | Chyu and Fang (2014)                         |
| New product development and selection problem                                      | Fuzzy AHP, Fuzzy TOPSIS                       | Saktivel et al. (2013)                       |
| Selection of the best biodiesel blend for IC engines                              | Fuzzy AHP, TOPSIS                             | Ghasssemi and Danesh (2013)                  |
| Desalination process selection                                                    | SWARA, VIKOR                                  | Zolfani et al. (2013b)                       |
| Assessment model of technologies | ELECTRE–4, MULTIMOORA, SWARA, VIKOR, TOPSIS | Zavadskas et al. (2013) |
|----------------------------------|------------------------------------------|------------------------|
| Prioritisation of advanced technology at NASA | Fuzzy AHP, Fuzzy TOPSIS | Tavana et al. (2013a) |
| Improving RFID adoption in Taiwan’s healthcare industry | DEMATEL, DANP, VIKOR | Lu et al. (2013a) |
| Equipment selection: key study of Gole Gohar iron mine | Fuzzy Sets; AHP; ANP; TOPSIS | Lashgari et al. (2012) |
| Manufacturing technology selection, an example of light emitting diode | DEMATEL, ANP, Fuzzy Delphi | Shen et al. (2011) |
| Software engineering decisions | AHP, Aggregation operators | Ribeiro et al. (2011) |
| Material selection with target-based criteria | ANP, VIKOR, DEMATEL | Liu et al. (2014) |
| Application of decision methods for avice innovation system construction | Fuzzy AHP, VIKOR | Chen and Chen (2010) |
| Evaluating vehicle telematics system | DEMATEL, ANP, TOPSIS | Lin et al. (2010a) |
| Sourcing strategy in IT projects | DEMATEL, ANP | Tsai et al. (2010a) |
| Combining classifiers to natural textured images | FC, parametric and non-parametric Bayesian approaches | Guijarro and Pajares (2009) |
| Machine tool selection | TOPSIS, Fuzzy AHP | Önut et al. (2008) |
| Evaluating service strategies of mobile network operators | AHP | Fu et al. (2007) |
| Evaluating intertwined effects in e-learning programmes | AHP, DEMATEL | Tzeng et al. (2007) |

**Grey Relational Analysis (GRA); Adaptive Neuro-Fuzzy Inference System (ANFIS); Analytic Hierarchy Process (AHP); Multiple Criteria Decision Making (MCDM); DEMATEL-based ANP (DANP); Decision-Making Trial and Evaluation Laboratory (DEMATEL); Multiobjective Optimisation by Ratio Analysis plus Full Multiplicative Form (MULTIMOORA); Analytic Network Process (ANP); Interpretive Structural Modelling (ISM); Fuzzy Inference System (FIS); Variable consistency dominance-based rough set approach (VC-DRSA); ViseKriterijumska Optimizacija I Kompromisno Resenje (in Serbian), that means Multicriteria Optimisation and Compromise Solution (VIKOR); Step-wise Weight Assessment Ratio Analysis (SWARA); Weighted Aggregated Sum Product Assessment (WASPAS); Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS); Benefits, Opportunities, Costs, and Risks (BOCR); Multiple Objective Decision Making (MODM); Data Envelopment Analysis (DEA); Triangular Fuzzy Numbers (TFNs); Fuzzy Axiomatic Design (FAD); Compromise Programming (CP); COmplex PRoportional ASsessment (COPRAS) and Complex PRoportional ASsessment with grey numbers (COPRAS-G); ELimination Et Choix Traduisant la REalité, that means ELimination and Choice Expressing Reality (ELECTRE); Fuzzy Clustering (FC).**

Source: Created by the authors.
management. Note that many HMCDM models are developed and applied for evaluating and selecting suppliers and improving green supply chain management.

A comprehensive review of literature on supplier selection with the help of diverse MCDM methods was presented in a review paper in 2013 (Chai, Liu, & Ngai, 2013). Meanwhile, in 2014–2015 there were many new developments and applications in the area of green manufacturing and supply chains. The five most frequently used techniques in HMCDM (ANP, DEMATEL, AHP, TOPSIS, and VIKOR demonstrated in Figure 7) are also the most frequently applied for supply problems in sustainable environments. Green manufacturing practices can be explored and the best one selected with the assistance of a HMCDM model combining DEMATEL based on ANP (DANP) with PROMETHEE (Govindan, Kannan, & Shankar, 2015). Because uncertainty is involved, the use of fuzzy numbers with MCDM methods VIKOR or DEMATEL is suggested for evaluation of green supply management practices (Rostamzadeh, Govindan, Esmaeili, & Sabaghi, 2015; Tsui, Tzeng, & Wen, 2015). The responsibility of identifying common drivers of green manufacturing is investigated by applying fuzzy AHP (Govindan, Diabat, & Madan Shankar, 2015). Evaluating alternative green suppliers and the selection of the best one demands the development of criteria and the application of optimisation models (Kannan, Govindan, & Rajendran, 2015). As for energy issues, a hybrid model for evaluating suppliers with regard to carbon and energy management performance is presented with an example of a hotel company. Performance criteria are identified using the FDM, and next, the DANP is applied to weight the criteria. Finally, VIKOR is used to evaluate the suppliers (Hsu, Kuo, Shyu, & Chen, 2014). The green supplier selection in the construction of a thermal power plant is addressed by applying a hybrid fuzzy Entropy – TOPSIS approach (Zhao & Guo, 2014).

Table 5. Research Area of HMCDM: Location.

| The problem solved                                           | Method***                                                                 | Authors                                                                 |
|--------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------|
| Selection with emphasis on sustainability                    |                                                                           |                                                                        |
| Offshore wind farm site selection                            | Fuzzy ANP, fuzzy DEMATEL, fuzzy ELECTRE                                   | Fetanat and Khorasaninejad (2015)                                      |
| Selecting the most suitable space for leisure in an urban site| Fuzzy AHP, DANP, GIS                                                     | Pourahmad et al. (2015)                                                |
| Improving GIS-based solar farms site selection               | DEMATEL, DANP, ANP, COPRAS–G                                              | Chen et al. (2014)                                                     |
| Greenhouse locating                                          |                                                                           | Rezaeiniya et al. (2012)                                               |
| Other topics                                                 |                                                                           |                                                                        |
| Selection of location as real estate brokerage services      | DANP, VIKOR                                                               | Lee (2014)                                                            |
| Shopping mall locating                                      | SWARA, WASPAS, AHP, COPRAS–G                                             | Hashemkhani Zolfani et al. (2013a)                                    |
| Forest roads locating                                       |                                                                           | Hashemkhani Zolfani et al. (2011)                                     |
| Selecting locations in an uncertain environment              | TOPSIS, Fuzzy ANP, DEMATEL                                               | Kuo and Liang (2011)                                                   |
| The most suitable site selection for an international distribution centre | TOPSIS, ANP, Fuzzy DEMATEL                                               | Kuo (2011)                                                            |
| Measures and evaluation for environment watershed plans      | ANP, DEMATEL, NRM                                                        | Chen et al. (2010)                                                    |

***Analytic Network Process (ANP); Decision-Making Trial and Evaluation Laboratory (DEMATEL); ELimination Et Choix Tra-duisant la Réalité, that means ELimination and Choice Expressing Reality (ELECTRE); Analytic Hierarchy Process (AHP); DE-MATEL-based ANP (DANP); Geographic Information System (GIS); COMplex PRoportional ASsessment with grey numbers (COPRAS-G); ViseKriterijumska Optimizacija i Kompromisno Resenje (in Serbian), that means Multicriteria Optimisation and Compromise Solution (VIKOR); Step-wise Weight Assessment Ratio Analysis (SWARA); Weighted Aggregated Sum Product Assessment (WASPAS); Network relation map (NRM).

Source: Created by the authors.
| The problem solved                                                                 | Method*** | Authors                                      |
|----------------------------------------------------------------------------------|-----------|----------------------------------------------|
| Dealing with sustainability issues                                                |           |                                              |
| Risk analysis of hot environment for foundry industry                             | ANP and linguistic fuzzy approach | Ilangkumaran et al. (2015)                   |
| A group DSS for ranking of alternatives with emphasis on corporate social responsibility | Delphi, DEMATEL, ANP, MDS       | Wang et al. (2015)                           |
| Investigation of drivers for corporate social responsibility implementation in the mining industry | Fuzzy DEMATEL | Govindan et al. (2014)                        |
| Environmental protection issue with an example of sustainable ecotourism          | DSM, DEMATEL | Chuang et al. (2013)                         |
| Assessing and selecting district revitalization projects                          | FDM, ANP  | Wang et al. (2013)                           |
| Improve senior citizens’ participation in recreational sports                     | ANP, DEMATEL | Chen and Sun (2012)                         |
| Improving tourism policy implementation                                            | DEMATEL, ANP, VIKOR             | Liu et al. (2012)                            |
| Relationship model and performance evaluation of hotels                           | Balanced scorecard, ANP, DEMATEL | Chen et al. (2011)                           |
| Evaluating companies’ environmental knowledge management under uncertainty       | ANP, DEMATEL | Tseng (2011a)                               |
| Evaluating corporate social responsibility programmes and costs in a hotel        | DEMATEL, ANP, ZOGP, ABC         | Tsai et al. (2010b)                          |
| Other topics                                                                      |           |                                              |
| Systematic approach to the project portfolio-selection problem                    | MDM, DEMATEL, ANP               | Jeng and Huang (2015)                        |
| SMEs management problems                                                          | Fuzzy DEMATEL, Fuzzy ANP, TOPSIS | Uygun et al. (2015b)                        |
| Review of MCDM approaches based on interval type-2 fuzzy sets, including hybrid methods applying IT2FSs | Hybrid approaches applying IT2FSs | Celik et al. (2015)                          |
| Exploring mobile banking services                                                 | DEMATEL, DNP, VIKOR             | Lu et al. (2015b)                            |
| Evaluating performance of internet banking branches                               | Fuzzy AHP, COPRAS-G             | Ecer (2015)                                 |
| Evaluation of risks in emerging capital markets                                   | Fuzzy AHP-TOPSIS, VIKOR         | Hacigüloğlu and Dincer (2015)               |
| Analysing service quality                                                         | Fuzzy ANP, VIKOR                | Hsu (2015)                                  |
| Internal control of procurement circulation                                        | DEMATEL, VIKOR, DNP             | Chen (2015)                                 |
| Supporting performance improvement of the banking industry                         | DNP, VIKOR                      | Shen and Tzeng (2015a)                      |
| Measuring the performance of companies                                            | DEMATEL, Fuzzy VIKOR            | Tavana et al. (2015)                        |
| Projects selection                                                                | Fuzzy Delphi, ANP, Fuzzy DEA    | Chang (2015)                                |
| The cause of accidents and a role of human factor in maritime accidents            | DEMATEL, ANP                    | Ozdemir and Guneroglu (2015)                |
| Evaluating strategy of SMEs                                                        | DEMATEL, ANP                    | Lu et al. (2015a)                           |
| Information technology disaster recovery site selection                            | DEMATEL, ANP                    | Yang et al. (2015)                          |
| Organisational value co-creation                                                  | DNP, fuzzy DEMATEL              | Chuang et al. (2015)                        |
| Performance evaluation of oil producing companies                                 | COPRAS, ANP                     | Rabbani et al. (2014)                       |
| Financial performance evaluation of companies                                     | Fuzzy ANP, VIKOR                | Safaei Ghadikolaei et al. (2014)             |
| Ranking of manufacturing companies based on their financial performance           | Fuzzy ANP, fuzzy VIKOR          | Khalili Esbouei et al. (2014)               |
| Group selection of a chief accounting officer                                      | AHP, fuzzy VIKOR                | Kersuliené and Turskis (2014)               |
| Prioritising the investment strategies in the presence of uncertainty             | AHP, DEMATEL, TOPSIS            | Yazdani-Chamzini et al. (2014)              |
| Selecting strategies for risk assessment                                           | TOPSIS                          | Lin et al. (2014)                           |
| Evaluation of entrepreneurial intensity among the SMEs                             | Fuzzy AHP, VIKOR, TOPSIS        | Rostamzadeh et al. (2014)                   |
| Encouraging entrepreneurial policies                                              | ANP, VIKOR                      | Tsai et al. (2014)                          |
| 4P’s planning in marketing                                                        | AHP, FMD                         | Gürbüz et al. (2014)                       |

(Continued)
| The problem solved                                                                 | Method****                                                                 | Authors                                                                 |
|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------|
| Six Sigma project selection                                                       | DEMATEL, ANP, VIKOR                                                       | Wang et al. (2014)                                                     |
| Market segmentation and evaluation, selecting the best market for a company         | SWARA, COPRAS-G                                                           | Aghdaie et al. (2013)                                                  |
| Private Primary School assessment                                                  | DEMATEL, ANP                                                             | Durmusoglu (2014)                                                     |
| University selection by assessing students' preferences                            | ANP, PROMETHEE                                                            | Kabak and Dağdeviren (2014)                                           |
| Improvement in economics and business                                              | VIKOR, DANP                                                              | Peng and Tzeng (2013)                                                  |
| Social media platform selection                                                    | Fuzzy ANP, COPRAS-G                                                      | Tavana et al. (2013)                                                  |
| Electronic government readiness assessment                                         | ANP, TOPSIS                                                              | Tavana et al. (2013)                                                  |
| Advertisement strategy selection                                                  | FAHP, TOPSIS-G                                                           | Hashemkhani Zolfani et al. (2012)                                     |
| Preparing a strategic framework for services in global market environments         | ANP, DEMATEL                                                             | Lee et al. (2012)                                                     |
| Assessing customer retention strategies                                          | DEMATEL, ANP                                                            | Jeng and Bailey (2012)                                                |
| The interactive trade decision–making research                                    | DEMATEL, ANP                                                            | Wang (2012)                                                           |
| Brand marketing for creating brand value                                           | DEMATEL, ANP, VIKOR                                                      | Wang and Tzeng (2012)                                                 |
| Assessing working strategies in a construction company                             | Fuzzy ANP, fuzzy COPRAS, BOSCR                                            | Fouladgar et al. (2012)                                               |
| Online reputation management for improving marketing                              | DEMATEL, DANP                                                            | Hung et al. (2012)                                                    |
| Evaluating website quality of accounting firms                                    | Fuzzy ANP, Fuzzy VIKOR                                                   | Chou and Cheng (2012)                                                 |
| Ranking universities                                                              | ANP, VIKOR                                                               | Wu et al. (2012)                                                      |
| Performance evaluation of education centres in universities                       | ANP, VIKOR                                                               | Wu et al. (2011)                                                      |
| Creating aspired intelligent assessment systems for teaching materials            | DEMATEL, ANP, VIKOR                                                      | Chen and Tzeng (2011)                                                 |
| Evaluating strategies of web–based marketing in the airline industry             | ANP, DEMATEL, VIKOR                                                      | Tsai et al. (2011)                                                    |
| Assessing service quality expectations                                           | DEMATEL, TOPSIS                                                          | Tseng (2011b)                                                         |
| Evaluating entrepreneurship policy evaluation for small and medium enterprises    | DEMATEL, ANP, ZOGP                                                       | Tsai and Kuo (2011)                                                   |
| Developing a model for assessing cost and quality                                 | ANP, DEMATEL                                                             | Tsai and Hsu (2010)                                                   |
| Firms' competence evaluation                                                      | ANP, fuzzy TOPSIS                                                        | Amir et al. (2009)                                                   |

****Analytic Network Process (ANP); DEcision-MAking Trial and Evaluation Laboratory (DEMATEL); Multidimensional Scaling (MDS); Interpretive Structural Modelling (ISM); Fuzzy Delphi Method (FDM); VisKriterijumska Optimizacija i Kompromisno Resenje (in Serbian), that means Multicriteria Optimization and Compromise Solution (VIKOR); Zero One Goal Programming (ZO GP); Activity-Based Costing (ABC); Modified Delphi method (MDM); Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS); DEMATEL-based ANP (DANP); Analytic Hierarchy Process (AHP); Fuzzy Metric Distance (FMD); Additive Ratio Assessment (ARAS); Step-wise Weight Assessment Ratio Analysis (SWARA); COMplex PRoportional Assessment (COPRAS) and COMplex PRoportional Assessment with grey numbers (COPRAS-G); Benefit, Opportunities, Cost and Risk (BOCR).

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The next important issue dealing with sustainable production and consumption is summarised in Table 4. HMCDM methods are successfully applied for technologies development and selection as well as for product development and selection. In the recent review, energy, environment, and sustainability were ranked as the areas that have most frequently applied MCDM approaches (Mardani et al., 2015). Regarding HMCDM applications, energy issues are also analysed frequently. The benefits of renewable energy in terms of environmental protection and economic viability are evaluated by applying a combination of Entropy and fuzzy GRA (Zhao & Guo, 2015). The prioritisation of renewable energy sources and technologies and the analysis of benefits, opportunities, costs, and risks (BOCR) in combination with ANP is provided (Kabak & Dağdeviren, 2014b). After deciding on the best renewable energy source, assessment of a region’s priority for implementation of projects can be made with the help of HMCDM (Vafaeipour, Hashemkhani Zolfani, Morshed Varzandeh, Derakhht, & Keshavarz Eshkalag, 2014). Further, an assessment of building energy performance involving a number of criteria is important (Kabak, Köse, Kürılmaz, & Burmagoğlu, 2014) for further designing effective energy systems by combining multi-objective optimisation and MCDM (Perera, Attalage, Perera, & Dassanayake, 2013). Numerous applications of adaptive neuro-fuzzy inference systems and fuzzy MCDM methods in problems related to renewable energy systems are summarised (Suganthi, Iniyan, & Samuel, 2015). A review of off-grid electricity supply technologies and methodologies for making sustainable energy sourcing decisions is also presented (Bhattacharyya, 2012). As for the increased awareness concerning environmental protection in waste treatment, evaluating health care waste treatment technologies by applying DEMATEL, MULTIMOORA and fuzzy sets is provided (Liu, You, Lu, & Chen, 2015a), and selecting the best plastic recycling technology by combining AHP and TOPSIS methods is suggested (Vinodh, Prasanna, & Hari Prakash, 2014).

After prioritising renewable energy sources and technologies, the suitability of a site for project implementation should be evaluated considering multiple, usually conflicting criteria (Table 5). Moreover, the data for assessment of location performance of the construction site involve subjective attributes and weights of the attributes which are usually expressed in linguistic terms. This makes fuzzy logic a more natural approach to these kinds of problems (Önüt, Kara, & Efendigil, 2008). For these reasons, fuzzy ANP, fuzzy DEMATEL and fuzzy ELECTRE methods for offshore wind farm site selection are applied (Fetanat & Khorasaninejad, 2015). A hybrid method involving DEMATEL and DANP for improving solar farms site selection is used (Chen, Huang, & Tsuei, 2014). Greenhouse locating is analysed from the aspects of physical conditions and natural environment, regional economy, and social environment. ANP is applied to find the relative significance of the identified criteria with an emphasis on interdependent relationships; the COPRAS-G method is applied to rank the regions and to select the best location for a greenhouse (Rezaeiniya, Zolfani, & Zavadskas, 2012). Focusing on the social context, the location of such services as recreation is important. Selection of the best leisure space in an urban site is made by using a powerful tool, i.e., a combination of HMCDM models, involving fuzzy AHP and DANP, and geographical information systems (GIS) (Pourahmad et al., 2015).

A number of papers employing HMCDM are aimed at company management, including both internal and external environment evaluations. The current papers consider economic viability without compromising sustainability issues; social and environmental responsibility are commonly discussed topics. As can be seen from Table 6, the most frequently applied MCDM methods in the following hybrid extensions are ANP and DEMATEL, which serve...
both crisp and fuzzy environments. The mentioned methods are applied in various industries: for risk analysis in the foundry industry due to its hot environment (Ilangkumaran, Karthikeyan, Ramachandran, Boopathiraja, & Kirubakaran, 2015) or risk analysis in Public Private Partnership projects (Valipour et al., 2015) for corporate social responsibility implementation in the mining industry (Govindan, Kannan, & Shankar, 2014), and for performance evaluation of hotels (Chen, Hsu, & Tzeng, 2011). The methods are suggested to be applied for ranking alternatives of corporate actions with a positive impact on the environment and stakeholders (Wang, Yang, & Lin, 2015). Human and environmental aspects are considered in developing and evaluating strategies in tourism (Chuang, Lin, Chen, & Chen, 2013; Liu, Tzeng, & Lee, 2012), and in recreational sports (Chen & Sun, 2012). Managing a company’s environmental knowledge is a complex uncertain process and requires a number of qualitative and quantitative measurements. A hybrid approach is proposed involving fuzzy sets to describe the subjective linguistic evaluations, including ANP to evaluate interdependence among the criteria and DEMATEL to fix the relations (Tseng, 2011a,b).

4. Conclusion

MCDM methods can be useful to support evaluation and selection processes and to help improve the overall sustainability of industries and organisations. Because sustainability is a natural subject of multiple criteria analysis, it is often classified into three sub-sets of criteria, involving economics, environmental, and social aspects. During the last few years, combining two or more methods to solve the same multiple criteria problem (HMCDM) has been used increasingly to support decision-making. A decision-maker or a group of decision-makers can be more confident in the results when HMCDM is applied, especially in cases of increasing variety and complexity of information as well as when facing more challenging problems. The current research discusses the advantages of hybrid approaches over individual methods, establishes general trends and main domains of application, and promotes the future use of HMCDM to address sustainability issues.

Considering distribution of application of HMCDM based on publication years, it is observed that application increases every year by a growing percentage. Eighty-four per cent of articles in the area have been published during the last five years, and articles of the last two years account for 50%, respectively. Accordingly, we can presume the increasing interest in current methods in the near future.

Considering the distribution of research by country of origin, it is interesting to note that some countries display a disproportionate application of HMCDM approaches. However, a deeper analysis reveals that particular scientific schools and highly referenced international collaborations explain the dominance of particular countries. While HMCDM methods have been applied by researchers affiliated in 34 countries, we find the greatest number of applications of MCDM (455) and of HMCDM (103) from Taiwan. The next most commonly represented countries are Iran (with 38 publications on HMCDM), Turkey (26), China (25), and Lithuania (22).

Attempting to determine which MCDM methods have been used the most frequently in developing hybrid approaches, we find that the most popular are the well-known methods that feature strong mathematical backgrounds and valuable characteristics, namely AHP, ANP, and DEMATEL (separately or as DANP), TOPSIS, and VIKOR. Each of the methods
was applied from 57 up to 110 times in all documents as well as from 48 up to 93 times in articles. The other methods were applied much less frequently.

Exploring application areas of HMCDM related to sustainability issues, it was observed that research dominates in evaluating and selecting suppliers and improving green supply chain management.

After comprehensive analysis of journal articles it was found that the five most frequently used techniques in HMCDM are also the most frequently applied for supply problems in more or less certain or vague environment, namely ANP, DEMATEL, AHP, TOPSIS and VIKOR. Crisp methods or fuzzy and grey approaches have been applied to improvise green manufacturing strategies and to select suppliers in green supply chain management.

The next important issue dealing with sustainable production and consumption is technology development and selection as well as product development and/or selection. A significant proportion of papers is devoted to evaluation of renewable energy sources and technologies. The next numerous group of papers analyse advanced waste treatment technologies. Regarding methods used in HMCDM, the current group of applications is characterised by more varied approaches, including Entropy, SWARA, WASPAS, GRA, and MULTIMOORA.

After prioritising technologies, selecting the suitability of a site for project implementation is evaluated considering economically, environmentally and socially friendly issues in changing and risky environments. This makes a fuzzy logic or grey numbers a more natural approach. Therefore it was observed that fuzzy ANP, fuzzy DEMATEL, fuzzy ELECTRE, COPRAS-G combinations were applied to this kind of problems involving uncertainty. A special feature for location problems is hybridisation of MCDM methods with GIS.

To help improving sustainability of industries, a number of papers employing HMCDM are aimed at company management, dealing with economic viability without compromising sustainability issues as social and environmental responsibility. As can be seen from the analysis, the most frequently applied MCDM methods in hybrid extensions for aforementioned problems were ANP and DEMATEL, in both crisp and in fuzzy environments.

In summary, because individual MCDM methods can yield different rankings, selecting an appropriate method is a great challenge. It is therefore recommended to use a hybrid approach based on more than one method and to integrate those results for final decision-making. Another advantage of hybrid approaches over individual methods is based on an opportunity of integrating subjective and objective criteria importance into the value of utility function. Simultaneously applying fuzzy logic can help to overcome uncertainties arising from human qualitative judgements, incomplete preference relationships, and to bring a model closer to real-life representation.

The findings of the current research confirm that applications of HMCDM approaches for sustainability issues are gaining a higher recognition due to their ability to effectively assist decision-makers in handling miscellaneous and varied information. Due to the increasing variety and complexity of information, it seems that the number of articles on the topic will be fast-growing and also will be used in other domains of sustainability.

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