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REVIEW ARTICLE

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

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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.

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JEL CLASSIFICATION
C4; C44; C46

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.

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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, Albadvi, 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, Matthiasehrgott, 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, Liias, & 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 (HMCDM) methods, including those for supporting overall sustainability and for promoting their usage in modern decision-making. Because HMCDM 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.

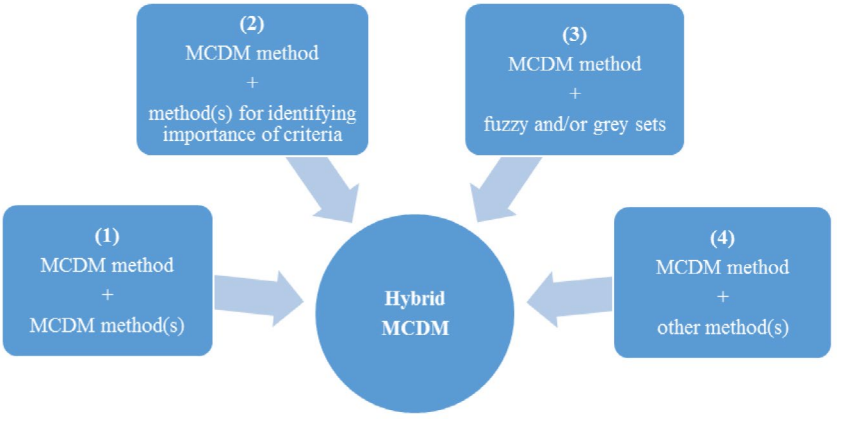

Figure 1. Composition of hybrid MCDM. Source: Created by the authors.

(2) 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.
(3) 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).
(4) 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?

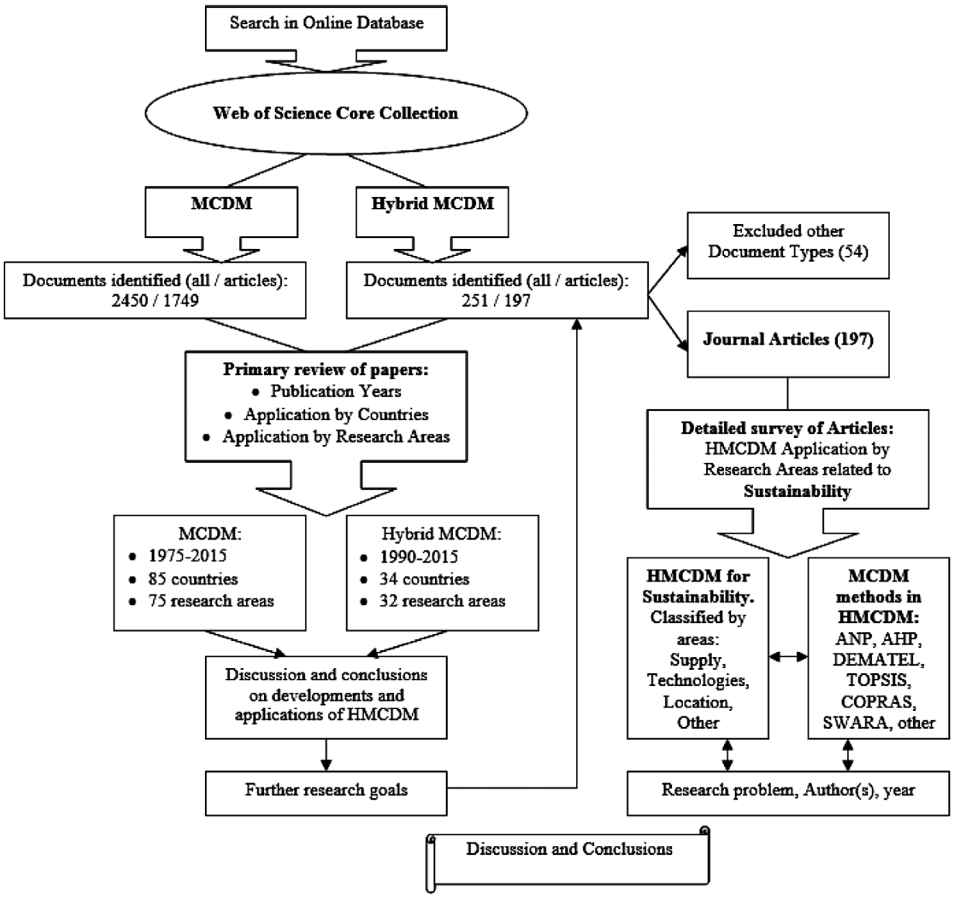

Figure 2. Summarised procedure of the research. Source: Created by the authors.

(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.

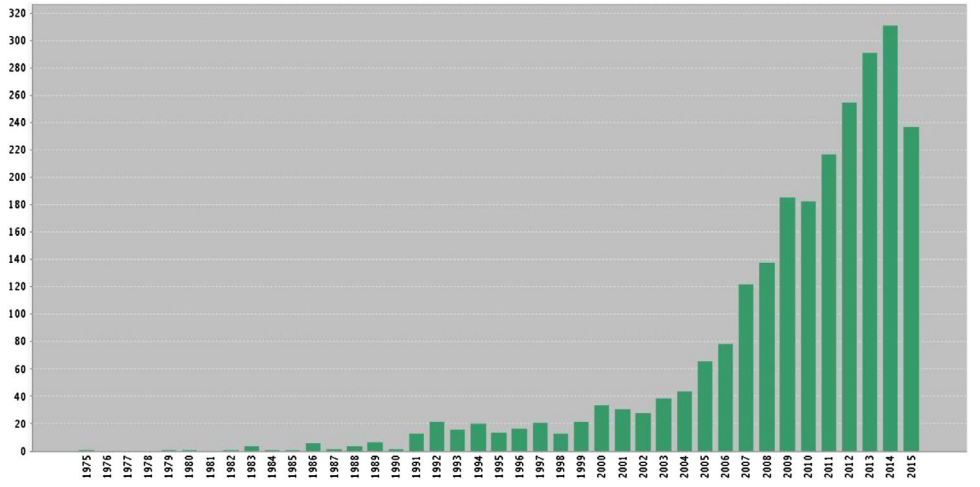

Figure 3. Number of publications on the topic of MCDM (total: 2,450). Source: Created by the authors.

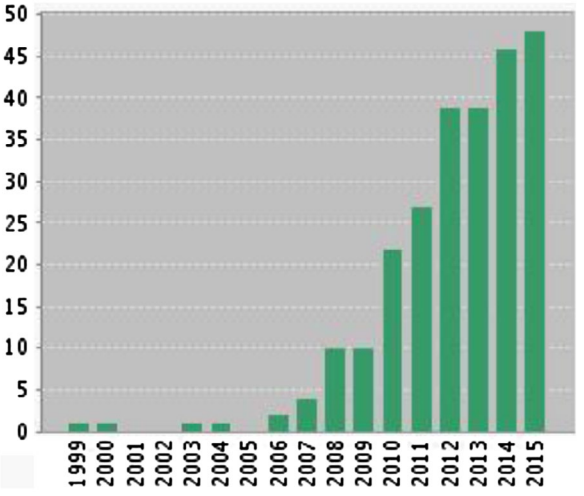

Figure 4. Number of publications on the topic of hybrid MCDM (total: 251). Source: Created by the authors.

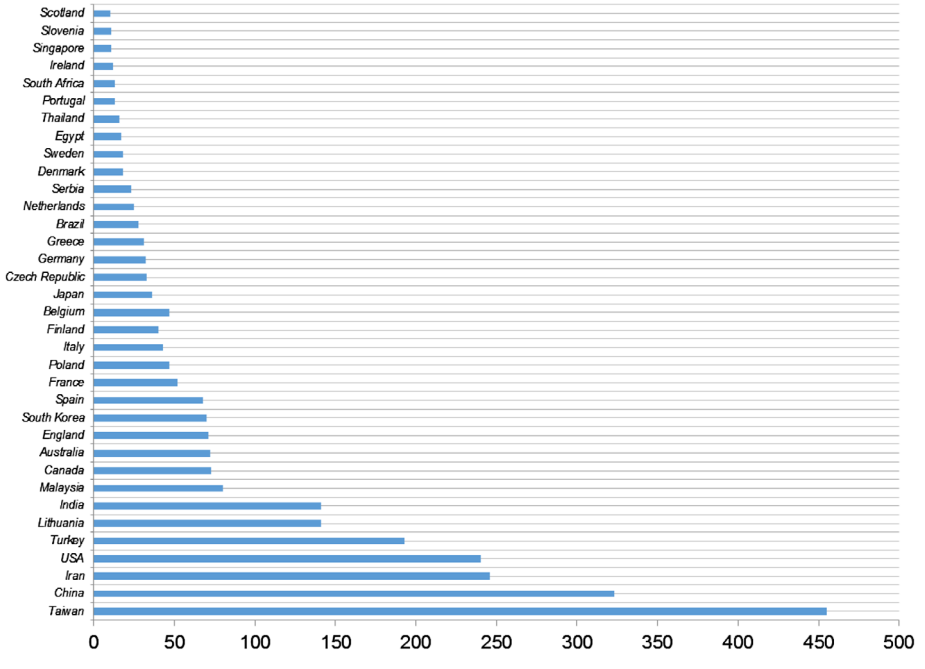

Figure 5. MCDM application by country of origin (number of publications). Source: Created by the authors.

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

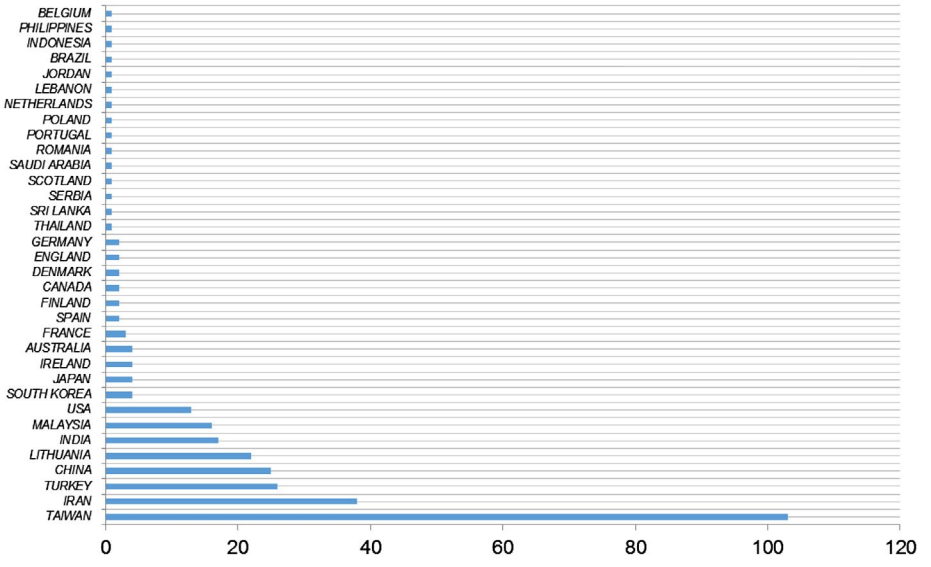

Figure 6. Hybrid MCDM application by country of origin (number of publications). Source: Created by the authors.

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

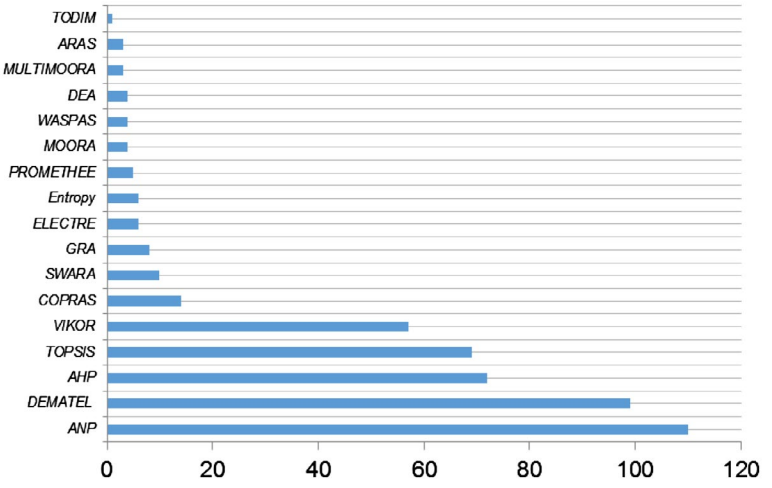

Figure 7. The use of the MCDM methods in hybrid MCDM methods. Source: Created by the authors.

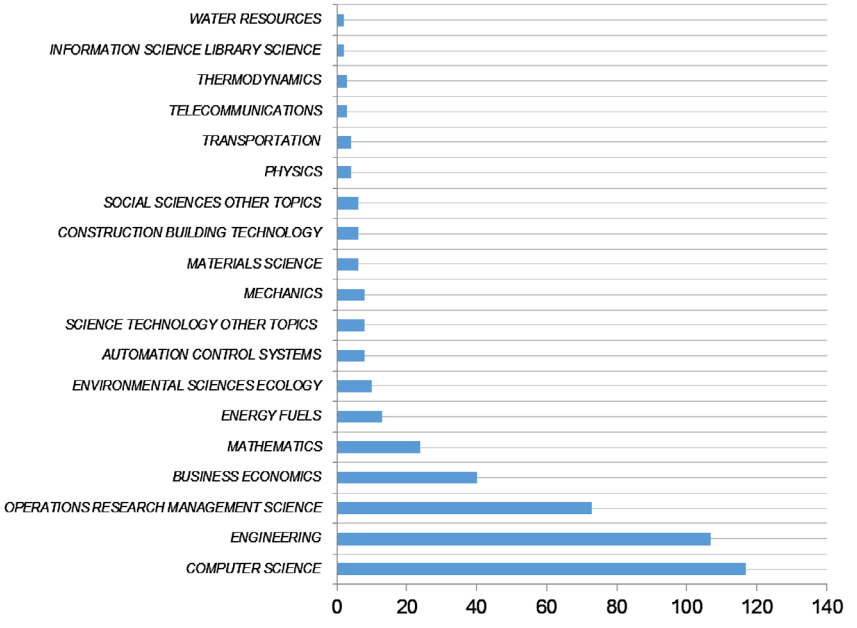

Figure 8. Number of publications by Research Areas on the topic of hybrid MCDM. Source: Created by the authors.

articles). 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 journal papers 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.

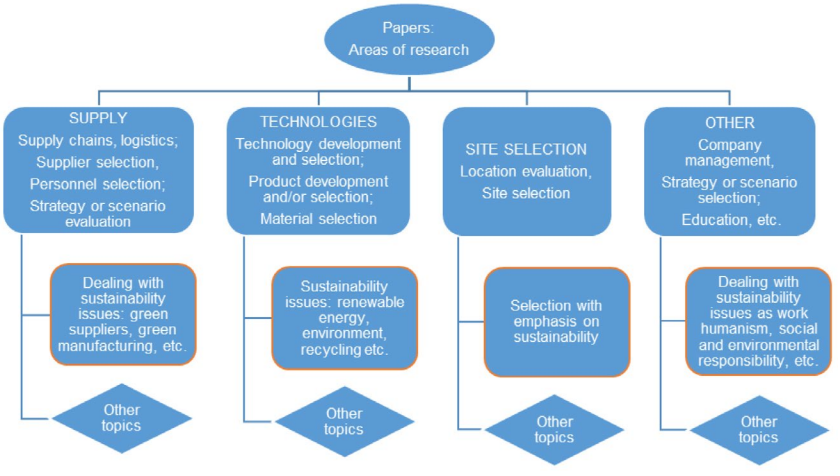

Figure 9. Research Areas of selected hybrid MCDM methods. Source: Created by the authors.

Table 3. Research Area of HMCDM: Supply.

The Problem Solved	Method*	Publication
Dealing with sustainability issues		
Evaluation of green manufacturing practices	DANP, PROMETHEE	Govindan et al. (2015)
Evaluation of green supply chain management practices by measuring the uncertainty of activities and solving the MCDM problem	VIKOR, TFNs	Rostamzadeh et al. (2015a)
Evaluation of alternative suppliers and selection of the best one	FAD	Kannan et al. (2015)
Simulation of drivers for better adoption of green manufacturing	Fuzzy AHP	Govindan et al. (2015)
Improving the performance of green suppliers in crystal display industry	PROMETHEE, INRM	Tsui et al. (2015)
Selection of sustainable supplier lot-sizing order	Fuzzy AHP, MODM	Azadnia et al. (2015)
Decision-making under uncertainty in green supply chain problems	Fuzzy DEMATEL	Wu et al. (2015)
Modelling green supplier selection	DANP, VIKOR	Kuo et al. (2015)
Supply chain environmental performance evaluation	ELECTRE, VIKOR, Grey numbers	Chithambaranathan et al. (2015)
Low carbon supplier selection in hotel industry	FDM, DEMATEL, DANP, VIKOR	Hsu et al. (2014)
Selecting green supplier of thermal power equipment	Fuzzy TOPSIS; fuzzy Entropy	Zhao and Guo (2014)
City logistics concept selection	Fuzzy DEMATEL, fuzzy ANP, fuzzy VIKOR	Tadić et al. (2014)
Review of literature on supplier selection	AHP, ANP, DEA, ELECTRE, PROMETHEE, TOPSIS, VIKOR	Chai et al. (2013)
Using a novel hybrid MCDM approach to evaluate green suppliers	Fuzzy DEMATEL, fuzzy ANP, fuzzy TOPSIS	Büyüközkan and Çifçi (2012)
Selecting the vendor selection for recycled material	DANP, VIKOR	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	ANP, Intuitionistic fuzzy TOPSIS	Rouyendegh (2015)
Material routing optimization in supply chain	Fuzzy AHP, TOPSIS, GA	Rostamzadeh et al. (2015b)
Evaluating different strategies in supply	SWARA-WASPAS, game theory	Hashemkhani Zolfani et al. (2015)
Supplier selection	Semi-fuzzy SVDD	Guo et al. (2014)
Supplier evaluation and improvement	ANP, DEMATEL, DANP, Fuzzy integral	Liou et al. (2014b)
Third-party logistics selection problem	FST, AHP, ANP, TOPSIS, ISM, VIKOR, DEMATEL, QFD, ELECTRE, Utility theory	Aguezzoul (2014)
Human resources performance evaluation	ANP	Gürbüz and Albayrak (2014)
Personnel selection	Fuzzy DEMATEL, Fuzzy ANP	Kabak (2013)
Supplier selection with interdependent criteria	AHP, TOPSIS	Kasirian and Yusuff (2013)
Model for supplier selection	Fuzzy Delphi, TOPSIS, ANP	Wu et al. (2013)
Supplier selection in continuously changing environment	SWARA, VIKOR	Alimardani et al. (2013)
Selection of an outsourcing provider	DEMATEL, DANP, GRA	Hsu et al. (2013)
Enterprise resource planning	DEMATEL, ANP	Tsai et al. (2013)
Logistics tool selection	DEMATEL, Fuzzy TOPSIS	Büyüközkan et al. (2012)
Personnel selection for teamwork	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	ANP	Lin et al. (2010b)
Strategic vendor selection	TOPSIS, ANP	Shyur and Shih (2006)

*DEMATEL-based ANP (DANP); 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 REalité, 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.

Table 4. Research Area of HMCDM: Technologies.

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)
Modelling new product development and applying in industry	Fuzzy ANP, ISM	Chen et al. (2015)
Financial evaluation of the IT industry	DEMATEL; FIS, VC-DRSA	Shen and Tzeng (2015b)
Determining vehicle telematics systems product or service	DEMATEL; ANP; VIKOR	Lin (2015)
Assessment of regions priority for implementation of solar projects	SWARA, WASPAS, Delphi	Vafaeipour et al. (2014)
Selecting the best plastic recycling method	AHP, TOPSIS	Vinodh et al. (2014)
Assessing building energy performance	Fuzzy ANP	Kabak et al. (2014)
Prioritisation of renewable energy sources	ANP, BOCR	Kabak and Dağdeviren (2014b)
Designing energy systems by combining MODM and MADM	Fuzzy TOPSIS, MODM	Perera et al. (2013)
Efficiently allocating energy resources in the case of high oil prices	Fuzzy AHP, DEA	Lee et al. (2013)
Improving environmentally oriented strategies for green innovation performance	Fuzzy D ANP, VIKOR	Lu et al. (2013b)
Review of methodologies for off-grid electricity supply decisions	Different methods, including HMCDM	Bhattacharyya (2012)
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	Ahmadi 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	Bitarafan 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	TOPSIS	Roya and Niaki (2014)
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	Sakthivel et al. (2013)
Desalination process selection	Fuzzy AHP, TOPSIS	Ghassemi 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)

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 aviatic 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.

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	Chen et al. (2014)
Greenhouse locating	ANP, COPRAS–G	Rezaeiniya et al. (2012)
Other topics		
Selection of location as real estate brokerage services	DANP, VIKOR	Lee (2014)
Shopping mall locating	SWARA, WASPAS	Hashemkhani Zolfani et al. (2013a)
Forest roads locating	AHP, COPRAS–G	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 Traduisant la REalité, that means ELimination and Choice Expressing Reality (ELECTRE); Analytic Hierarchy Process (AHP); DEMATEL-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.

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 6. Other Research Areas applying HMCDM.

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	ISM, 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, DANP, 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	Hacioglu and Dincer (2015)
Analysing service quality	Fuzzy ANP, fuzzy VIKOR	Hsu (2015)
Internal control of procurement circulation	DEMATEL, VIKOR, DANP	Chen (2015)
Supporting performance improvement of the banking industry	DANP, VIKOR	Shen and Tzeng (2015a)
Measuring the performance of companies	DEMATEL, Fuzzy ANP, Fuzzy DEA	Tavana et al. (2015)
Projects selection	Fuzzy Delphi, ANP, TOPSIS	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	DANP, fuzzy DEMATEL	Chuang et al. (2015)
Performance evaluation of oil producing companies	COPRAS, ANP	Rabbani et al. (2014)
Financial performance evaluation of companies	FAHP, fuzzy VIKOR, fuzzy COPRAS, fuzzy ARAS	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 ARAS	Keršulienė 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 entrepreneurship policies	ANP, VIKOR	Tsai et al. (2014)
4P's planning in marketing	AHP, FMD	Gürbüz et al. (2014)

(*Continued*)

Table 6. (*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 (2014a)
Improvement in economics and business	VIKOR, DANP	Peng and Tzeng (2013)
Social media platform selection	Fuzzy ANP, COPRAS–G	Tavana et al. (2013b)
Electronic government readiness assessment	ANP, TOPSIS	Tavana et al. (2013c)
Advertisement strategy selection	FAHP, TOPSIS-G	Hashemkhani Zolfani et al. (2012c)
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	AHP, fuzzy TOPSIS	Amiri 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); VIseKriterijumska Optimizacija I Kompromisno Resenje (in Serbian), that means Multicriteria Optimization and Compromise Solution (VIKOR); Zero One Goal Programing (ZOGP); 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, Derakhti, & Keshavarz Eshkalag, 2014). Further, an assessment of building energy performance involving a number of criteria is important (Kabak, Köse, Kırılmaz, & Burmaoğlu, 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 (Önut, 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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