APPLICATION OF MULTI-CRITERIA DECISION ANALYSIS IN THE AREA OF SUSTAINABILITY: A LITERATURE REVIEW

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ABSTRACT

Multi-Criteria Decision Analysis is a decision-making technique that is used by practitioners and frequently discussed and applied by researchers. This present study attempts to review the literature of applications of MCDA techniques in the area of sustainability using citation analysis. For the data collection, the Scopus database was used. With the help of related keywords, 701 research papers were identified and found suitable for analysis. These papers were then analyzed based on country, author, citation, year, and other criteria to demonstrate the pattern of research applying MCDA in sustainability. The CiteSpace tool was also used to present the clusters, citation analysis, and keywords as bursts. The findings of the present study will help future researchers better explore the field.

Keywords: Citation analysis; CiteSpace; multi-criteria decision analysis; sustainable development; and sustainability.

1. Introduction

If the phrase ‘citation analysis’ is searched on Google Scholar, it yields about 4,850,000 results (Sheoran et al., 2018). After browsing a few pages, it becomes evident that this technique has been applied in many disciplines. The field of sustainability is also not untouched as far as the application of citation analysis is concerned. Various studies have been conducted using citation analysis to gain insights from the field of sustainability (Schoolman et al., 2012; Tang et al., 2018). However, the authors were unable to find a single study on the application of this technique in the combined field of MCDA and sustainability.

MCDA has been used very frequently to solve complex decision-making issues in the shortest time possible (Alitaneh, 2019). Most decision-making situations involve many factors, and therefore, MCDA techniques are becoming very important. MCDA includes many analytical techniques such as AHP, DEMETAL, ELECTRE, VIKOR, Value Analysis, PROMETHEE, and Rough Set (Gonzalez & Pradenas, 2019). Several studies have used Fuzzy extensions and hybrids to solve MCDA-based problems (Ghorabaee et al., 2017).

It is worth mentioning here that previous studies have found a growing trend of research in sustainability (Mura et al., 2018; Tang et al., 2018). It has become increasingly important to take the field of sustainability deeper to provide direction to future researchers. Moreover, the area of sustainability has yet to be explored to the core. Therefore, the present study explores and investigates the application of MCDA and sustainability through citation analysis. The paper begins with a brief review of the literature and then discusses the methodology of the study. The chosen studies are segregated based on several criteria to gain insights. The paper concludes with a discussion, implications, and directions for future research.

2. Literature review

Past studies have explored different functional areas of sustainability using a citation analysis-based approach. Recently, Tang et al. (2018) broadly reviewed the field of sustainability with the help of 6,459 papers published from 2009-2018 using citation analysis. Schoolman et al. (2012) also examined the interdisciplinary nature of the field of sustainability using citation analysis by segregating the literature based on three dimensions of sustainability, i.e., environmental, economic, and social. Chabowski et al. (2011) explored the sustainability marketing literature from 1958-2010. Liu et al. (2017) and Ruiz-Real et al. (2019) took the field of sustainability marketing further using a citation analysis approach and studied sustainability from the consumption and retail perspectives, respectively. Fu et al. (2016) performed a citation analysis to dig deeper into sustainability operations and allied areas. All of these studies are limited because they only discover the link between sustainability and different management streams such as marketing, operations, and general management, and none of them were able to establish the connection of sustainability with any of the methods.

As far as the application of citation analysis in the area of sustainability and MCDA techniques is concerned, Taticchi et al. (2015) studied the application of MCDA to the area of the sustainable supply chain management. Similarly, Kumar et al. (2017) also explored the use of MCDA techniques in the area of sustainable and renewable energy management. Pohekar and Ramachandran (2004) restricted the scope of their study to a single MCDA technique, i.e., the Analytical Hierarchy Process (AHP), to investigate the field of sustainable energy management. These studies also made some focused efforts to review the literature on sustainability and MCDA.

This review identified some gaps in the limited literature available on the subject. The past studies were either too broad or too narrow to study the sustainability literature. The

field of sustainability has been explored in some specific directions. Moreover, previous studies had a very limited scope from the perspective of MCDA techniques. Therefore, it is evident from the above discussion that there is a need to perform a comprehensive analysis of the literature, taking into account the application of MCDA techniques in the field of sustainability.

3. Methodology

In this paper, we reviewed a total of 701 scientific articles published in refereed journals focusing on MCDA techniques. For simplicity, this review paper focuses on "multi-criteria decision analysis" as a single search item because using every technique as a search item would have increased the complexity of the results. This paper intends to classify articles based on country context, year of publication, citations, journal name, etc. The methodology for the present research has been adopted from Sheoran et al. (2018). Data were sought through the Scopus database using keywords like "multi-criteria decision analysis" OR "MCDA" and "sustainability" or "sustainable". The papers were selected using the keywords sustainability OR sustainable in Title of Document AND Multi Criteria Decision analysis OR MCDA in Title, Abstract, and Keywords in the Scopus database.

3.1 CiteSpace methodology

This present study sought to develop a comprehensive list of MCDA articles published from 1996 to 2018 in the area of sustainability. Elsevier's Scopus database was used to extract the data for this study, which is "the largest abstract and citation database of peer-reviewed literature: scientific journals, books, and conference proceedings. Delivering a comprehensive overview of the world's research output in the fields of science, technology, medicine, social sciences, and arts and humanities, Scopus features smart tools to track, analyze and visualize research." (Elsevier, 2018)

The number of journals covered under the Scopus database is one of the motivating factors to use it. The Scopus database provides information such as author, title, abstract, affiliating institute, country, keywords, funding agency, and so on. This present study used the Citespace tool to visualize research patterns and trends in MCDA research. "These data can be used to conduct temporal and spatial analysis, analysis of word co-occurrence, co-authorship analysis, and co-citation analysis." (Jiang et. al, 2019, p. 1931). The articles related to MCDA from 1996 to 2018 were retrieved from the Scopus database. The search was based on the keywords "Multi-criteria decision analysis" or "MCDA".

4. Analysis and findings

4.1 Major subject area coverage

The present research shows a significant number of papers that cover various domains. The concept of sustainability or sustainable development has implications in various subject areas including engineering, physical sciences, social sciences, medical,

agricultural, etc. The highest numbers of papers have been published in the area of environmental science followed by social sciences and engineering, respectively (See Table 1). The domain areas of business, management and accounting, and energy also have a significant number of publications. It is worth mentioning that some of the studies may have been cross-listed in multiple disciplines resulting in the number of individual studies exceeding the total number of studies.

Table 1
Subject area coverage with the number of publications

Area (Related to Sustainability and MCDA)	**Number of Papers**
Environmental Science	400
Social Sciences	213
Engineering	209
Energy	192
Business, Management and Accounting	157
Agricultural and Biological Sciences	70
Computer Science	63
Decision Sciences	57
Economics, Econometrics and Finance	46
Earth and Planetary Sciences	30
Mathematics	20
Chemical Engineering	15
Materials Science	13

Area (Related to Sustainability and MCDA)	**Number of Papers**
Multidisciplinary	11
Biochemistry, Genetics and Molecular Biology	9
Medicine	7
Chemistry	8
Arts and Humanities	5
Psychology	5
Physics and Astronomy	3
Immunology and Microbiology	1
Pharmacology, Toxicology and Pharmaceutics	1

4.2 Publications by year

As far as the evolution of sustainability (and/or sustainable development) is concerned, researchers began publishing papers in this area in 1996 (Kumar et al., 2013). Initially, there were very few publications (Figure 1). From 1996 to 2012, an up and down trend can be observed; however, this area saw stable growth from 2011 to 2014. Exponential growth in the number of publications can be seen after 2014 and surprisingly, a drop in number publications was seen in 2018. This may be due to a delay in updating publications on the Scopus database. It can be safely said that there has been significant growth in the number of publications in this field in the current decade.

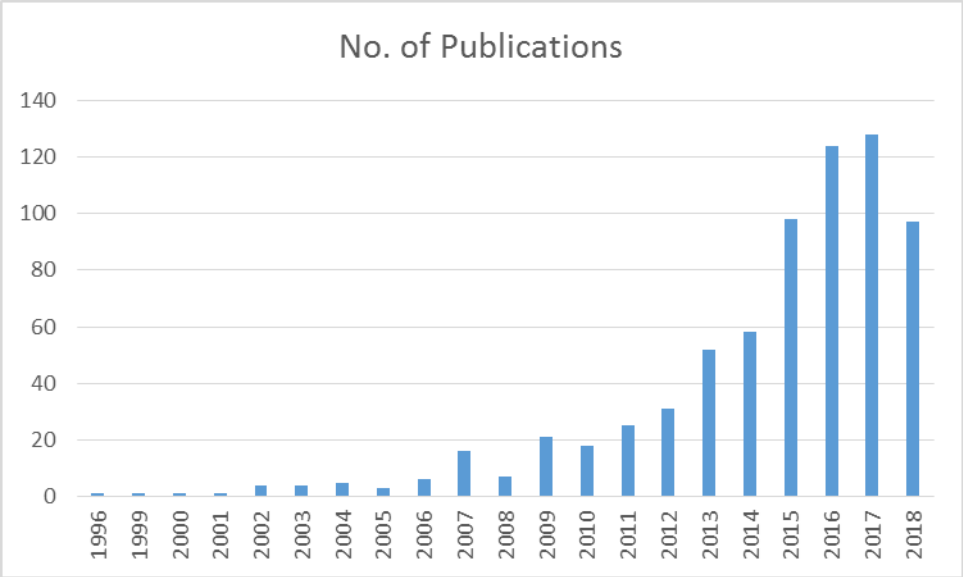

Figure 1 Yearly publication distribution

4.3 Publications by country

This section provides a list of the number of publications by country and as many as 951 countries are represented as can be seen in Figure 2. Seventy-nine nationalities are represented (plus 7 undefined) in the 701 publications. As far as the affiliation of authors is concerned, India is the country that has published the most on sustainability using MCDA techniques with 95 publications, followed by China (89), the United States (83), and Iran (51). For example, the first article in this area (2005) was published in *Energy* by two authors, Ranjan K. Bose and G. Anandalingam, from India and the USA, respectively. This paper was on the topic of "Sustainable urban energy-environment management with multiple objectives." This is an example of cross-country research that is very common in the area of sustainability since it is a global issue.

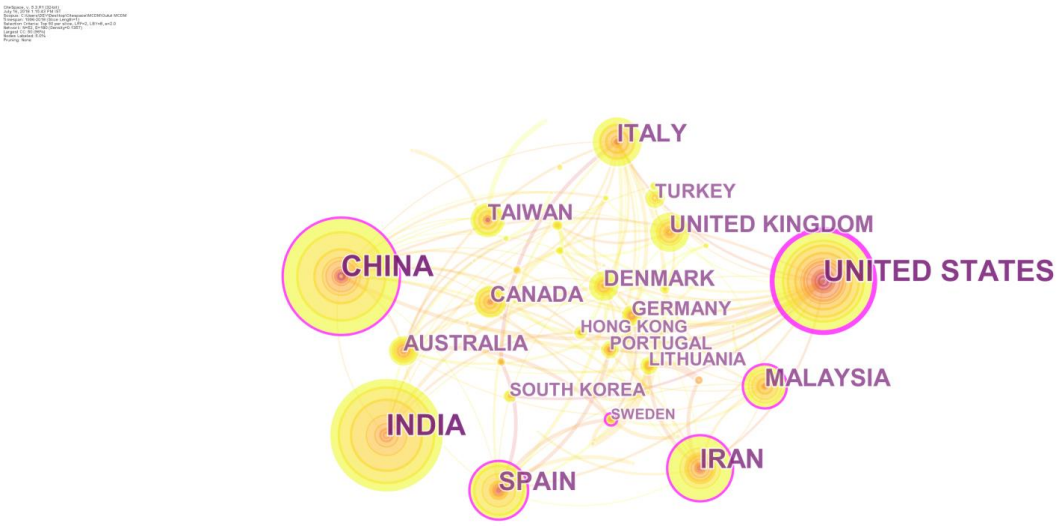

Figure 2 Publications by country

4.4 Journal and citation trends

Appendix 1 provides information about the various journals where sustainability-related work has been published using MCDA techniques. These journals belong to very diverse areas such as forestry, agriculture, energy, environment, ecology, transportation, operations research, waste management, wastewater, and many others. The journals, *Sustainability* (Switzerland), *Journal of Cleaner Production*, *Journal of Environmental Management*, *Energy*, *Energy Policy*, and *International Journal of Sustainable Development and World Ecology* have a large number of publications in the area of sustainability combined with the MCDA technique. However, the majority of the work has been published in core sustainability journals and researchers can target some core field journals. This is also evidence that the area under study is well accepted among journals from different subjects.

Figure 3 shows the prominence of different journals based on the number of citations. The size of the circle indicates the number of citations each journal received from other journals. Similarly, the nodes represent the citation pattern among the journals. *European Journal of Operation Research*, *Journal of Cleaner Production*, and *Expert System with Application* are the journals that have been frequently cited by their counterpart journals. The journals *Energy Policy*, *Energy*, *Omeg*a, and *Sustainability* also look promising in terms of the number of citations.

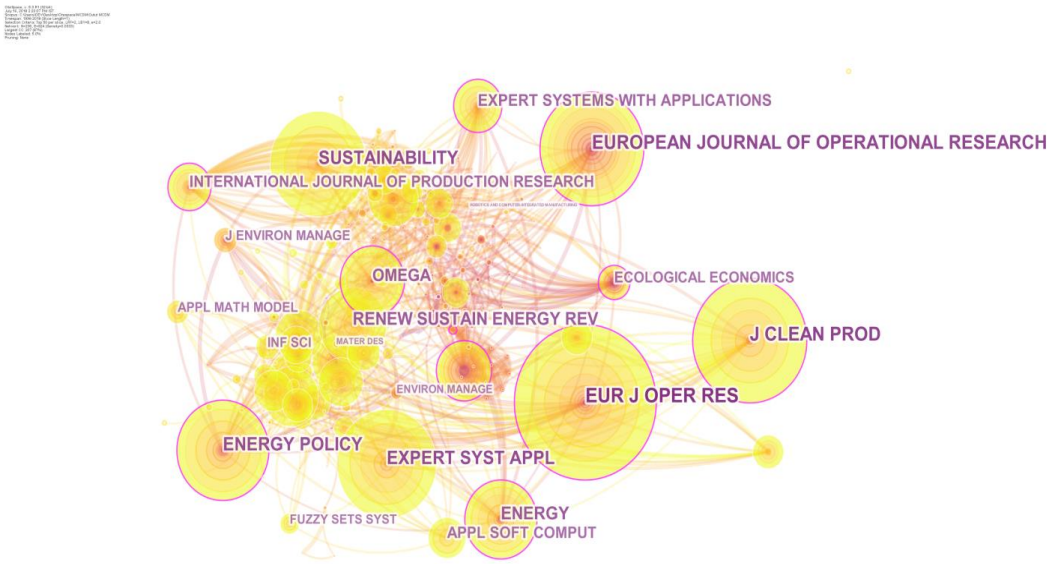

Figure 3 Journal citation trends

4.5 Author with the most publications

Thomas L. Saaty is the most cited author in this field of the present area under the investigation. This is not surprising since Saaty developed the concept of the AHP. Figure 4 shows other authors with significant contributions in this field of research. Recently, Govindan, K. has become a prominent author in this area. As seen in Figure 4, other authors who have contributed significantly to the area under study include Sarkis, J., Zahed, L.A., Hwang, C.L., Zhu, Q., Kahraman, C., Seuring, S., Luthra, S., Singh, R.K., Mathiiyazhagan, K., Diabat, A., Awasthi, A., etc.

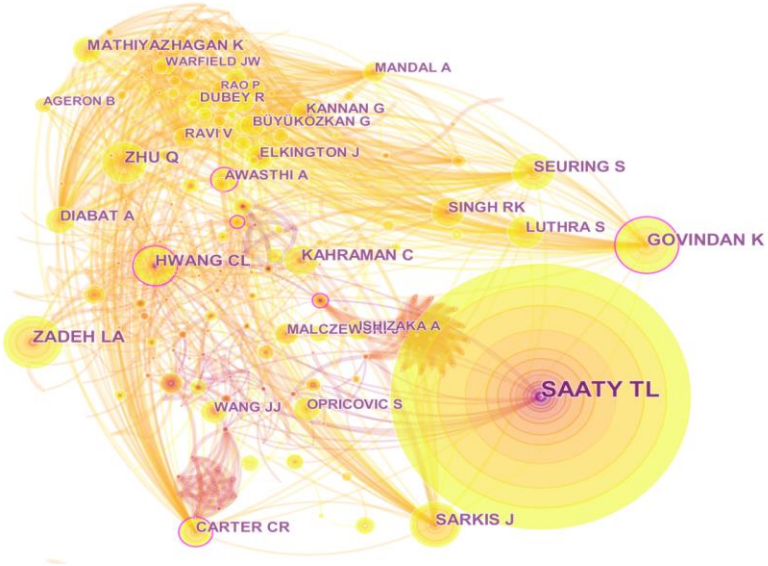

Figure 4 Authors with the most publications

4.6 Most cited articles

Among the 701 documents under consideration, the paper titled, "Quantitative models for sustainable supply chain management: Developments and directions" authored by Brandenburg et al. (2009) in the *European Journal of Operational Research* is the most cited document with a total of 307 citations. This is a review paper that focuses on the various quantitative models in the sustainable supply chain. Other papers that received more than 100 citations are shown in Table 2.

Table 2
Most cited articles

Publication Year	**Document Title**	**Journal**	**No. of Citations**
2014	Quantitative models for sustainable supply chain management: Developments and directions	European Journal of Operational Research	307
2007	Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis	International Journal of Production Research	193
2007	Development of composite sustainability performance index for steel industry	Ecological Indicators	177
2007	SAFE-A hierarchical framework for assessing the sustainability of agricultural systems	Agriculture, Ecosystems and Environment	157
2007	Key performance indicators and assessment methods for infrastructure sustainability-a South African construction industry perspective	Building and Environment	141
2009	Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process	Energy Policy	126
2008	Analysis of interactions among the barriers to energy saving in China	Energy Policy	105
2011	Advancing integrated systems modelling framework for life cycle sustainability assessment	Sustainability	104

Publication Year	**Document Title**	**Journal**	**No. of Citations**
2007	Developing a sustainability framework for the assessment of bioenergy systems	Energy Policy	104
2000	Multicriterion analysis for sustainable water resources planning: A case study in Spain	Water Resources Management	103

4.7 Most discussed keywords

The keywords of an article represent the focus area of the particular research. This section discusses the top keywords used most frequently in articles in the area of sustainability using MCDA techniques. Other than sustainability and sustainable development, "decision making" was the most discussed keyword from 2003 to 2005 as depicted in Figure 5. Further, the term "mathematical model" was another most discussed keyword from 2006 to 2007. Most of the keywords are related to decision making or MCDA techniques.

The citation burst revealed key words that increased significantly over a period of time (Figure 5). Keywords in the article in the combined file of articles were analyzed for their burstiness. The time interval is shown in blue and the timeline in which the keyword observed burstiness is shown in red. The red line shows the beginning and end of the burst. For example, the keyword 'decision making' started in 2003 and ended in 2005 with a burst strength of 4.7058. Hot keywords before 2007 belong to decision sciences, conservation of natural resources, and the geographical area of Asia and Eurasia. The term multi-criteria decision analysis first burst in 2009. Similarly, it can be observed that time-specific MCDM techniques, such as TOPSIS, started appearing in citation bursts in 2016.

The five most used keywords in the time zone view are shown in Figure 6. The keywords that were used the most in each year can be easily identified. For example, "multiple criteria decision support system" was used most in the year 2007 and it was again used prominently to search papers between 2007 and 2009. Moreover, this keyword was used quite considerably in 2010. In later years, this particular keyword has been used quite less than other keywords.

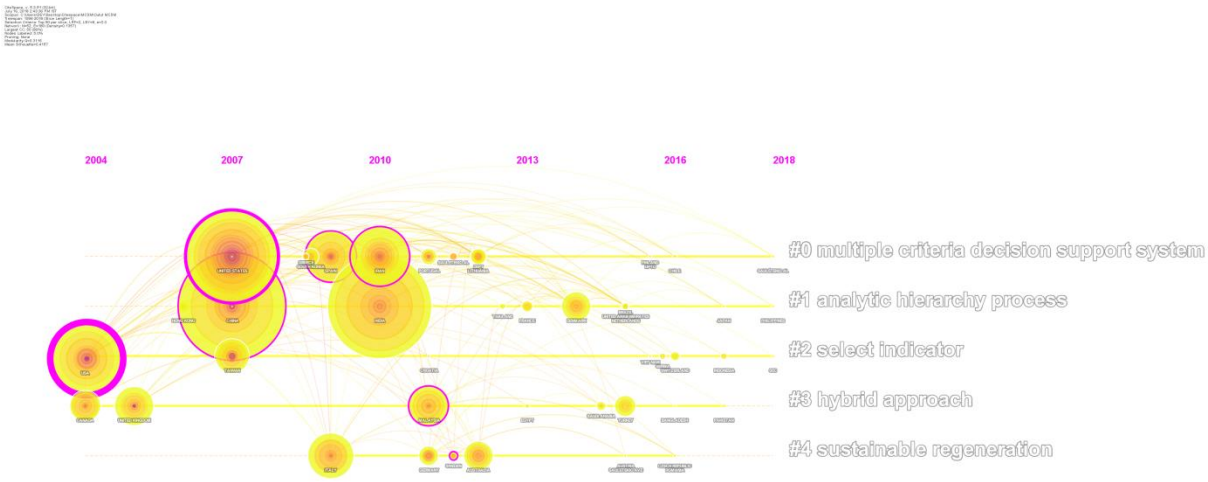

Figure 6 Top five keywords during different time zones

4.8 Clusters

The present study identified five thematic clusters with the help of the CiteSpace tool. The labeling of clusters and assignment of a particular number to clusters was done by CiteSpace only, which is not always in exact chronological order. According to Chen (2014), eligible clusters should have ten or more members in each cluster with a Silhouette value > 0.70. Silhouette values range from -1 to 1 and measure the quality of the configuration in clusters and the maximum value represents a complete solution (Jiang et. al, 2019). In the present study, four eligible clusters were identified according to the above-mentioned criteria. The authors have attempted to present and explain the summary of the four thematic clusters created by CiteSpace.

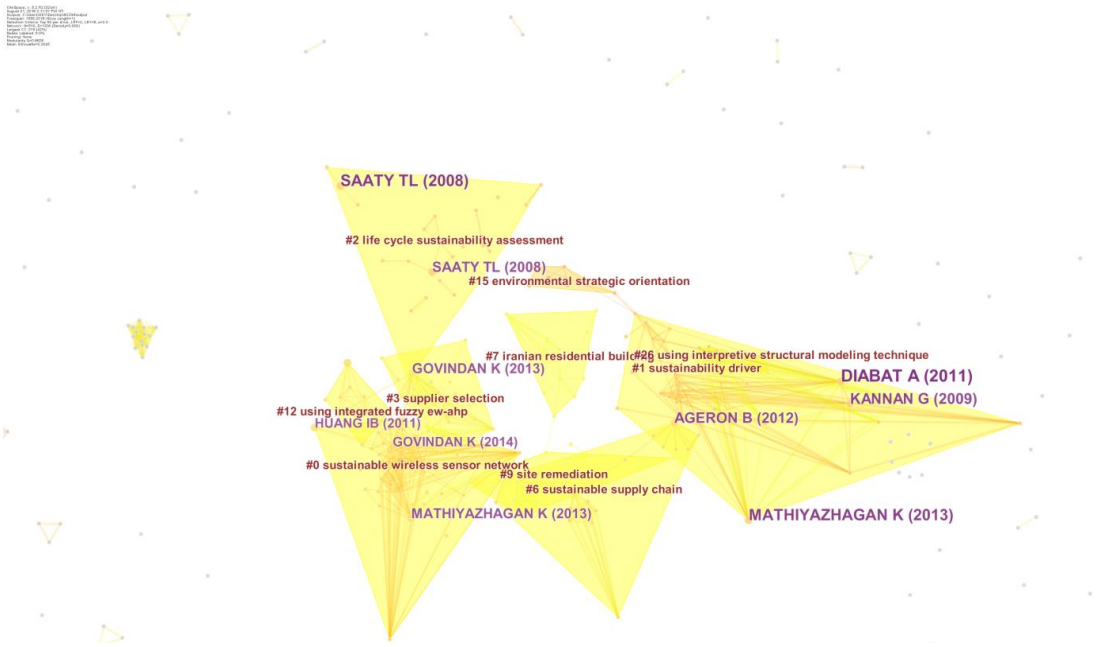

Figure 7 Cluster analysis using CiteSpace

Cluster 1: The biggest cluster (#0) has 49 members with a silhouette value of 0.89 and is categorized as the 'sustainable wireless sensor network'. The main keywords appearing in this cluster are composite sustainability performance index, fuzzy analytic hierarchy process, fuzzy multi-objective linear programming model, sustainable supply chain, and sustainable wireless sensor network. The most active citer to the cluster is Srie (2015) who contributed 0.5111 in the total silhouette value of this cluster.

Cluster 2: The second largest cluster (#1) has 41 members with a silhouette value of 0.923. and is categorized as the 'sustainability driver'. The main keywords that appear in this cluster are interpretive structural modeling technique, composite sustainability performance index, sustainability framework, sustainable manufacturing, and sustainable supplier selection. The most active citer to the cluster is (0.4441) Mehregan (2014).

Cluster 3: The third largest cluster (#2) has 38 members with a silhouette value of 0.945 and is categorized as a life cycle sustainability assessment. The main keywords that appeared in this cluster are sustainable development planning, disposal scenario, resources approach, intelligent transport system, and fuzzy AHP approach. The most active citer to the cluster is (0.13171) Foolmaun (2013).

Cluster 4: The fourth largest cluster (#3) has 26 members and a silhouette value of 0.949. It is labeled as supplier selection. The main keywords that appeared in this cluster are sustainability view, order allocation, construction method selection, environmental strategic orientation, and sustainability supplier selection criteria. The most active citer to the cluster is (0.3871) Badri (2017).

5. Discussion and conclusion

The present literature review considered 701 documents for software-based analysis. This review paper first identified the trends of publication in the area of 'sustainability with MCDA'. Several forms of analysis were used to understand the patterns in the area of sustainability with MCDA. The findings of the study suggest that there has been substantial growth in the number of publications in this area. However, some areas like arts and humanities, chemical engineering, chemistry, physics and astronomy, psychology, mathematics, immunology, and microbiology still need to be explored in terms of the application of MCDA in the field of sustainability. Further, areas like management science, earth and planetary science, ecology, climate change, economics, and accounting and finance are also underexplored and can be considered for future research. Future studies may also look at interdisciplinary and cross-country based studies.

The area of MCDA and sustainability is well regarded by journals and has seen a wide variety of publications. As far as journals related to the area under study are concerned, *Sustainability* (Switzerland) and *Journal of Cleaner Production* are the top two journals with 69 and 45 articles, respectively. Journal publishing trends will help readers identify journals where similar material can be found or published. Moreover, the list of the top 10 most cited articles is provided to understand the paper's contribution. The prominence of journals and authors in terms of their citations and publications will help budding researchers understand the importance of MCDA in sustainability and craft their research direction in a better way. The segregation of sustainability and MCDA into different clusters helps beginning researchers develop a better understanding of the field.

This research paper is a bibliographic source for the area of sustainability using MCDA techniques. Though search results provided publications from diverse fields, it also demonstrates the applicability of MCDA techniques in several areas of decision-making. This study has contributed to the literature by identifying research papers in the area of sustainability and the MCDA technique.

This present study has a few limitations. The authors only used two keywords, "MCDA" and "Multi-Criteria Decision Analysis". Many papers that had the acronym MCDA in their abstract and full text may have been omitted from the search result because the title-based query was run to search articles for the present study. Similarly, this review paper only focused on "Sustainability" OR "Sustainable", and many papers with related keywords like "environment" may have been missed. Future researchers may address these issues and can use more keywords to refine the search results.

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Appendix
List of Journals with Number of Publications

Journal Name	**Number of Publications**
Sustainability (Switzerland)	69
Journal of Cleaner Production	45
Journal of Environmental Management	18
Energy	12
Energy Policy	12
International Journal of Sustainable Development and World Ecology	10
Ecological Indicators	8
Resources Conservation and Recycling	8
Building and Environment	7
Clean Technologies and Environmental Policy	7
Environmental Modelling and Software	7
Renewable Energy	7
Resources Policy	7
Science of the Total Environment	7
International Journal of Life Cycle Assessment	6

Journal Name	**Number of Publications**
International Journal of Production Research	6
International Journal of Sustainable Engineering	6
Marine Policy	6
Sustainable Cities and Society	6
Water Resources Management	6
Benchmarking	5
Business Strategy and the Environment	5
Energies	5
Environmental Management	5
Global Journal of Flexible Systems Management	5
Land Use Policy	5
Biomass and Bioenergy	4
Cities	4
Ecological Economics	4
Environment Development and Sustainability	4
Environmental Monitoring and Assessment	4
Environmental Science and Policy	4

Journal Name	**Number of Publications**
European Journal of Operational Research	4
Expert Systems with Applications	4
International Journal of Advanced Manufacturing Technology	4
International Journal of Business Innovation and Research	4
Journal of Civil Engineering and Management	4
Journal of Modelling in Management	4
Management of Environmental Quality An International Journal	4
Transport	4
Transportation Research (Part D)- Transport And Environment	4
Applied Energy	3
Applied Mathematical Modelling	3
Applied Soft Computing Journal	3
Automation in Construction	3
Computers and Electronics in Agriculture	3
Industrial Management and Data Systems	3
International Journal of Environmental Research and Public Health	3
International Journal of Environmental Science and Technology	3

Journal Name	**Number of Publications**
Journal of Environmental Planning and Management	3
Journal of Infrastructure Systems	3
Journal of the Operational Research Society	3
Mathematical Problems in Engineering	3
Ocean and Coastal Management	3
Production Planning and Control	3
Progress in Industrial Ecology	3
Sustainability	3
Sustainable Production and Consumption	3
Technological Forecasting and Social Change	3
Applied Sciences Switzerland	2
Aquaculture International	2
Arabian Journal for Science and Engineering	2
Archives of Civil and Mechanical Engineering	2
Business Process Management Journal	2
Chemical Engineering Transactions	2
Competitiveness Review	2

Journal Name	**Number of Publications**
Computers and Industrial Engineering	2
Construction and Building Materials	2
Desalination	2
Energy and Buildings	2
Environmental Earth Sciences	2
Environmental Science and Pollution Research	2
Forest Ecology and Management	2
Integrated Environmental Assessment and Management	2
International Journal of Applied Decision Sciences	2
International Journal of Applied Engineering Research	2
International Journal of Logistics Systems and Management	2
International Journal of Process Management and Benchmarking	2
International Journal of Procurement Management	2
International Journal of Strategic Property Management	2
International Journal of Sustainable Society	2
International Journal of Sustainable Transportation	2
Journal of Air Transport Management	2

Journal Name	**Number of Publications**
Journal of Environmental Studies	2
Journal of Performance of Constructed Facilities	2
Journal of Sustainable Tourism	2
Journal of the American Water Resources Association	2
Journal of Urban Planning and Development	2
Journal of Water Supply Research and Technology Aqua	2
Management Research Review	2
Nature Environment and Pollution Technology	2
Omega United Kingdom	2
Procedia Manufacturing	2
Renewable and Sustainable Energy Reviews	2
Shengtai Xuebao Acta Ecologica Sinica	2
Stochastic Environmental Research and Risk Assessment	2
Structure and Infrastructure Engineering	2
Technological and Economic Development Of Economy	2
Uncertain Supply Chain Management	2
Waste Management and Research	2

Journal Name	**Number of Publications**
Water International	2
Water Policy	2
Water Switzerland	2
Wit Transactions on Ecology and the Environment	2
ACS Sustainable Chemistry and Engineering	1
Advanced Science Letters	1
Advances In Natural and Applied Sciences	1
African Journal of Agricultural Research	1
Agricultural Economics	1
Agriculture Ecosystems and Environment	1
Agroforestry Systems	1
Agronomy for Sustainable Development	1
Alexandria Engineering Journal	1
American Journal of Applied Sciences	1
American Journal of Environmental Sciences	1
Annals of Nuclear Energy	1
Annals of Operations Research	1

Journal Name	**Number of Publications**
Applied Ecology and Environmental Research	1
Applied Geography	1
Aquaculture Economics and Management	1
Arabian Journal of Geosciences	1
Archives of Environmental Protection	1
Archives of Mining Sciences	1
Arpn Journal of Engineering and Applied Sciences	1
Asia Pacific Journal of Tourism Research	1
Asian Journal of Scientific Research	1
Australian Journal of Civil Engineering	1
Biofuels Bioproducts and Biorefining	1
Bulletin of Marine Science	1
CIRP Journal of Manufacturing Science and Technology	1
Carpathian Journal of Earth and Environmental Sciences	1
Case Studies on Transport Policy	1
Chemical Engineering Research and Design	1
Chinese Geographical Science	1

Journal Name	**Number of Publications**
Chinese Journal of Population Resources and Environment	1
Civil Engineering and Environmental Systems	1
Coastal Management	1
Cogent Business and Management	1
Computational Economics	1
Computers and Operations Research	1
Computers and Structures	1
Computers Environment and Urban Systems	1
Corporate Ownership and Control	1
Croatian Journal of Forest Engineering	1
Decision Support Systems	1
Distributed Generation and Alternative Energy Journal	1
E A M Ekonomie A Management	1
Ecological Applications	1
Ecological Modelling	1
Ecology Environment and Conservation	1
Ecosystem Services	1

Journal Name	**Number of Publications**
Ecosystems	1
Educational Technology and Society	1
Energy Conversion and Management	1
Energy Education Science and Technology (Part A)- Energy Science and Research	1
Engineering Economics	1
Environment International	1
Environment Systems and Decisions	1
Environmental and Engineering Geoscience	1
Environmental Impact Assessment Review	1