Visualizing the Intellectual Structure of Risk Management in Renewable Energy Projects

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Abstract. The development of renewable energy (RE) is the evident solution to satisfy the increasing demand of sustainable development while respecting the environment and ensuring a green economic growth. RE is a highly complex emerging research field with fragmental and diversified traits. However, the massive generation of risk was increasingly threatening the sustainable development of RE projects. This paper fills this gap via a systematic and quantitative review. In order to identify and visualize the intellectual structure and research opportunities, we conducted the scientometric analysis method from dynamic and evolutionary perspective. A total of 448 articles published from 1997-2018 were collected to construct the knowledge map and comprehensive framework for RM. This study contributes to the existing RM-RE knowledge by visualizing the intellectual structure and presenting a comprehensive knowledge framework.

1. Introduction
The ever-growing increase in energy demand and the negative impact of fossil fuels on the environment underscore the need for renewable energy (RE) sources [1-3]. The development of RE sources – biomass, hydropower, wind, solar, geothermal, ocean, and waste – is a major strategy to mitigate climate change and has a significant impact on local environment and social conditions [4]. However, compared with traditional energy projects, RE projects often involve long life cycles, complex uncertainties, and they exert for-reaching impacts on risk management. To cope with the increasing complexity and difficulty of RE development, risk management (RM) has been developing at rapid pace and becoming extensively utilized [5]. Risk management in renewable energy (RM-RE) projects is one of the basic tools for preventing unwanted events as well as efficient and effective support tool in the process of project management. Numerous scholars have conducted research on the RM-RE, using various research paradigms and methods from different perspectives and disciplines. Most scholars focus on investigating key risks and strategies during the RM process, including risk identification, assessment, and mitigation [6]. In addition to assessing the RM process, scholars concentrate on quantifying policy risks associated with RE investment, incentive, and risk-return profiles. While scholars such as Ioannou et al., (2017) have reviewed the main research and best practice of RM-RE studies, they mainly focus on quantitative and semi-quantitative methods that have been used to model risks and uncertainties in RE [7]. This paper fills this gap via a systematic and quantitative review of RM-RE. Therefore, the main objectives of this study are: (1) to summarize RM-RE studies from 1997 to 2018; (2) to understand the holistic research status for RM-RE from the perspective of...
journal co-citation, keyword co-occurrence network, as well as to identify research theme-divisions through abstract term cluster analysis.

2. Materials and methods

We employed the scientometric analysis method to visualize the evolution of RM-RE researches. The wide spectrum and multiple disciplines of research topics in RM-RE has led to lack of manual and scientometric review in the whole field. Manual analysis is subjective, and the number of publications reviewed is limited. In addition, the relationship between publications cannot be quantified through manual review [8]. In contrast to manual review, scientometric review utilizes mathematical and statistical methods to quantitatively analysing the knowledge domain for a particular subject with large number of articles [9].

To review the intellectual structure and evolution of RM-RE projects, we first identified a list of academic journals that publishes RM-RE projects researches. To provide a comprehensive search, the list of publications was obtained from Web of Science (WoS). The WoS core database is considered to be the most authoritative database for studying literature in many fields [10], since it covers the most prestigious and important journals all over the world. Publication data was extracted from the WoS core collection database (SCI-EXPANDED, SSCI) in June 2019. The main conclusions of each paper should be determined by its research objectives, methodologies, and major contributions.

3. Results

3.1 Journal Co-Citation Network Analysis

Journal co-citation network analysis is an essential step to identify the key journals in a specific knowledge domain. Through journal co-citation network analysis, the most influential journals can be found, the similarities between journals can be discovered by finding the same references cited by journals. Thus, the most relevant references on a particular research subject can be identified. Figure 1 shows the journal co-citation network of RM-RE projects studies generated by CiteSpace with 147 nodes and 283 edges. Cited references are represented by nodes, the node volume is proportional to the citation number. The co-citation relationships are represented by edges between two nodes, and the edge thickness is proportional to closeness of the reference relationship. Larger node shows higher importance of the study, and thicker edge demonstrates closer relationship between two references. The main themes were labeled by highlighting the references in the co-citation network. Consisting with descriptive analysis, Energy Policy is the most cited journal with frequency equals to 155. As shown in Table 1, it is also meaningful to observe that Renewable and Sustainable Energy Reviews, which mainly publish papers with significant review element, includes widely influential journals in the field. The highest centrality is the Applied Energy with 0.31, which indicates the widest range of influence. With the concepts of sustainable development through renewable energy and risk management practice being widely spread and accepted, the RM-RE related research receives significant attention, paper published in Science drive related research greatly.
Figure 1. Journal co-citation network for RM-RE: 1997 – 2018. Notes: Top 5% cited journals were highlighted.

| Rank | Frequency | Centrality | Cited reference                        |
|------|-----------|------------|----------------------------------------|
| 1    | 151       | 0.10       | Energy Policy                          |
| 2    | 137       | 0.10       | Renewable and Sustainable Energy Reviews |
| 3    | 136       | 0.24       | Energy                                 |
| 4    | 128       | 0.31       | Applied Energy                         |
| 5    | 106       | 0.20       | IEEE Transactions on Power Systems     |
| 6    | 97        | 0.21       | Renewable Energy                       |
| 7    | 81        | 0.22       | Energy Conversion and Management       |
| 7    | 81        | 0.11       | IEEE Transactions on Smart Grid        |

The patterns and trends in the body of knowledge were identified by investigating the journal clusters. Cluster labels are selected from the noun phrases extracted from titles, keywords, and abstracts of the publication. Cluster labels are those top-ranked noun phrases. It is interesting to find that the clusters #0 energy resource, #2 public acceptance, #4 risk management are connected to each other within the network and are linked by various nodes (i.e. Energy Policy, Applied Energy, Energy, Renewable and Sustainable Energy Reviews, and so on). However, cluster #1 power generation is relatively isolated and is linked by IEEE Transaction on Power System, IEEE Transaction on Smart Grid, and IEEE Transaction on Sustainable Energy.

3.2 The keyword co-occurrence network
The analysis of keywords can identify important research themes in RM-RE projects, since keywords usually summarize the core content of the publications. The overall keyword co-occurrence network
demonstrates the development of RM-RE projects over time and shows the most critical footprints of this field.

Figure 2 shows the overall keyword co-occurrence network. The timespan, which indicates the size of the data, is 1997 to 2018. The time slice is set to one year. Nodes represent keywords that occurred more than twice in the 448 selected publications in this paper. Node size represents the keyword appearance frequency, whereas edge thickness represents the frequency at which two keywords are used at the same time. The timespan from past to present is marked by a transition of colour from a cool tone to warm tone.

![Keywords co-occurrence network: 1997 - 2018](image)

Notes: “renewable energy”, “risk management”, “risk”, and “management” are treated as stop-words and are excluded in this figure.

Four common keywords, namely, “renewable energy”, “risk management”, “risk” and “management”, were defined as the domain stop-words because they form a high percentage in the analysis domain [10]. These three stop-words were excluded because they are the fundamental concepts of RM-RE projects and they do not add substantial value to the present analysis. On the other hand, the frequency of these stop-words is much higher than other keywords. The high frequency will influence the interpretation of other significant keywords in Figure 2.

The most frequent co-occurrence keywords are model, system, and uncertainty appearing 63, 63, and 56 times, respectively (Figure 2). Model is the highest-ranking term, which shows that unlike former studies focusing on simple descriptive and statistical analysis methods, an increasing number of researches employ modelling technology (i.e. system dynamics, genetic algorithms, and integer programming model) to address complicated issues in discipline of RM-RE. The following high-frequent keywords “generation” (frequency=48), “optimization” (46), “market” (30), “impact” (28), operation (28), and demand response (23) represent the hot topics in RM-RE. As a widely concerned strategy for RE projects, the topic of RM has attracted the most research efforts, corresponding to the followed categories: (a) energy & fuels (168), (b) engineering (154), (c) environmental science & ecology (112), (d) science & technology (60), and (e) business & economics (58).
3.3. Cluster Analysis

Keyword co-occurrence analysis provided several general insights and hot spots of RM-RE researches. However, the knowledge structures of RM-RE studies cannot be classified by keyword frequency. Instead, cluster analysis can discover research patterns in the knowledge domain by utilizing a series of mathematical and statistical algorithms to transform collected data into several structured clusters [11].

As a tool for progressive knowledge domain visualization, CiteSpace provides various functions to facilitate the understanding and interpretation of network patterns. Cluster labels are automatically generated in CiteSpace by selecting the top-ranked words occurring in each cluster (Chen, 2006). As shown in Figure 3, 15 prominent research clusters are identified, such as demand response, public acceptance, restructuring. The cluster modularity is 0.6107 (modularity>0.3), and silhouette is 0.6925 (silhouette>0.5), indicating the structure obtained by clustering is significant, and the result is robust and credible.

![Cluster analysis in RM-RE: 1996 - 2018](image)

The size, silhouette, and top-ranked terms of each theme-cluster are shown in Table 2. Cluster size is the number of publications in each cluster, while silhouette represents cluster’s homogeneity. Silhouette values range from zero-to-one. The closer the Silhouette value is to zero, the lower the consistency of clustering members. The cluster analysis provides a more objective approach to perceive the overall structure of a certain knowledge domain than most previous subjective reviews, which is based on the understanding of a specific field from authors [12].

| Cluster | Size | Silhouette | Top terms |
|---------|------|------------|-----------|
| #0      | 40   | 0.563      | stochastic programming; renewable energy source; power generation |
| #1      | 34   | 0.682      | rare earth element; environmental impact; permanent magnet |
| #2      | 32   | 0.867      | distribution; conservation; probability; belief network |
As shown in Table 2, the most significant clusters, cluster #0 demand response, includes 40 articles. These publications refer to the management of demand side and power generation by using stochastic programming. Cluster #1 public acceptance related to the analysis of environmental impact, and uncertainty from supply and demand sides. The research themes of Cluster #2 and cluster #3 concentrate on modelling methods, such as Bayesian network, or monte carlo simulation. Cluster #4 life cycle assessment covers sensitivity analysis of impact and performance. From the perspective of profitability, Both Cluster #9 and Cluster #10 focus on economic evaluation and return. A few clusters, such as restructuring, are not noted in previous reviews, indicating that emphasis has been on the restructuring of the energy sector and energy supply in the last decade.

By comparing the main research topics from the co-occurrence analysis and cluster analysis, we find that there are some overlaps between the two results, such as demand response, uncertainty identification, and modelling methods. There are also some differences between them. For example, cluster analysis identifies some new research trends in the RM-RE projects, including restructuring, and life cycle assessment; whereas co-occurrence analysis reveals hot topics, such as market reaction, operation, and optimization. These two results complement each other and enrich the understanding of RM-RE projects.

4. Conclusions
The use of renewable energy is a major strategy to mitigate greenhouse gas emissions, reduce fossil fuel imports, and create a sustainable energy system, and has a profound socio-economic impact on society. However, integrating growing RM-RE projects researches face many challenges. The intellectual structure of RM-RE is highly multi-disciplinary which includes the risk management, technology development, system integration, and modelling technology from several areas.
A total of 448 papers were selected for journal co-citation analysis, keyword co-occurrence, cluster analysis, and burst detection, in order to provide a holistic knowledge summary of RM-RE. Energy Policy, Applied Energy, Energy, and Renewable and Sustainable Energy Reviews were identified as the four major journals associated with research on RM-RE. By measuring the high-frequent co-occurrence keywords, the major research topics in this area include model, system, and uncertainty. The following high-frequent keywords generation, optimization, market, impact, operation, and demand response represent the hot topics in RM-RE.

The contribution of this article to the body of knowledge is significant. This paper provides valuable guidance and in-depth understanding for researchers, practitioner and policy makers to promote RM-RE sustainability. The milestone findings of this study reflect the achievements of the exploration and development of RM-RE theory.

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