Network Analysis of Patenting Trends in Energy Efficiency

A Bogomolova\textsuperscript{1,2}, I Balk\textsuperscript{2}, E Semenov\textsuperscript{3} and N Ivaschenko\textsuperscript{1}

\textsuperscript{1} Lomonosov Moscow State University, GSP- 1, Leninskie Gory, Moscow, 119991, Russia
\textsuperscript{2} Global innovation Labs LLC, 258 Harvard Str #352 Brookline MA 02446 USA
\textsuperscript{3} Irkutsk National Technical Research University, 83 Lermontov Str 664074 Irkutsk Russia

E-mail: info@innovationlabs.net

Abstract. One of the most important topics of sustainability research and applications is reaching energy efficiency. In this paper we analysed more than 100,000 of patents related to different aspects of energy efficiency with the issue dates from 1973 to 2019. In the paper we will discuss how network theory can be applied to discover technology trends and apply them to improve sustainability efforts making more educated decision. This paper will demonstrate how patenting trends change with time and how different topics influence each other.

1. Introduction
Patent analysis is widely used method to analyze and predict technological and research trends in the field of sustainable development. Several articles where published addressing issues of electrochemical energy storage [1], low-carbon energy technologies [2] and renewable energy [3]. Such research is important for both policy-making consideration and approach and venture capital firms to make an informed decision of innovation performance and technological approaches. At the same time it gives engineers and technologists vision on which technologies will be dominating industrial landscape on the horizon of 5–7 years.

The greenhouse gas emission from the energy sector is expected to increase by 130% from 2005 levels by the year 2050 [4, 5]. This makes energy efficiency one of the key areas of innovation for sustainable development.

In this research we considered patents related to energy efficiency and issued from 1973 to 2019. For this study we analyzed more than 108,000 patents which where issued during this period worldwide. To demonstrate trends we split them into seven groups with the first group covering patents issues from 1973 till 1989 and the rest covering remaining period of time with five years steps. It worth to mention that number of patents in this field the rapidly increasing, especially in recent years. If for the first 16 years of study (1973–1989) only about 500 patents on renewable energy were issued, in the last five years frame of the study this number exceeded 47000. Therefore we can say that significant effort has been made to reach better energy efficiency, which is one of the key areas of sustainable development.
2. Methodology and data

For the purpose of this research we considered patent titles, or rather separate words in the titles, which correspond and define particular patent subject field. We did not consider prepositions, pronouns, conjunctions and other words that have no meaningful value for our study. The graph of word contextual interconnect was created with size of the noted reflecting words frequency and edges representing their interconnections. The size of a node indicates how many times a given word was used in the sample: the bigger the node, the more often the word is mentioned. The edges also have a different size: the thicker the edge between two nodes, the more often these words were used together. Based on this data, we were able to build a network for analyzing the most popular topics related to renewable energy by periods (Figure 1).

We used Newman modularity [6] to divide network into clusters based on the frequency of sharing use (edges). (Figure 1) Same node color indicates membership in the same cluster. As we can see, clusters are well distributed and fairly separated. Considering each cluster we can highlight the key areas of interest and research around them. During all periods of the study there were clusters formed around separate topics, which evolved and acquired new features and accents over time. We can see clear shift from natural gas and liquid fuel head system to fuel cell and solar technologies.

![Graph of word contextual interconnect](image)

| Period          | Modularity |
|-----------------|------------|
| 1973–1989       | 0.377      |
| 1989–1994       | 0.628      |
| 1994–1999       | 0.399      |
| 1999–2004       | 0.313      |
The next phase of the study was to research trends. In each period of study, we identified the most significant words and traced their evolution throughout periods (Figure 2). We can see a rapid increase in the number of references to some topics. However, this increase can be attributed to an increase in the total number of patents. At the same time there are some interesting findings worth to mention. Thus the number of patents dedicated to “delivery” and “formation” has not changed much over time indicating steady interest to this subject matter. At the same time we can see rapid increase is the number “power” related patents.

Figure 1. Clustering patents by period

e) 2004–2009
Modularity = 0.279

f) 2009-2014
Modularity = 0.288

g) 2014–2019
Modularity = 0.268
To better demonstrate patenting trends, let's take a slightly different approach—consider percentage of patents with titles containing the same keywords (Figure 3). This will give us a normalized and clearer picture of patenting trends. This approach emphasizes how interest in a particular topic evolved over time. For example, heat, gas, water, material, delivery were the most popular keywords in the first third of the study period (1973–1999). We continue to see use of these keywords in the later periods as well, but in different contexts as we can see on Figure 1. In the following 10 years (1999–2009), the most frequent keywords in issued patents were fuel, cell, acid, and energy treatment and formation. And since 2009 to the current time, the topics related to power, solar, and electric energy and its generation are rapidly gaining popularity.

Moreover, referring to Figure 1, we can see the context in which researchers are interested in the particular keyword. For example, for “power” related issues: the topics of interest are generation of electricity and heat, power plants; control systems and energy storage. Moving along the edges on the graph, we can understand the most popular directions of technological evolution. Moving from large to smaller nodes, we can demonstrate the subject matter in more details.
3. Conclusions and future research

We can see clearly see that research leading to better energy efficiency and therefore reaching sustainability goals is rapidly increasing over the last three decades. There was significant shift in the research topics from natural gas burning efficiency 1970s and 1980s to fuel cell and solar power related research in the last few years. It would be safe to mention that renewable energy related technologies are the main patenting trend in the energy efficiency related field. The next logical step for the current research would be used machine learning algorithms to predict patenting trends based on historical patent data and related scientific publications.

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