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Determination and Prioritization of Criteria for Urban Energy Resilience Using Fuzzy Analytic Hierarchy Process (FAHP)

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Abstract:
Today, around 60% of the world's population lives in urban areas. Cities are major consumers of energy, hence the building of urban energy resiliency is essential.
Resiliency of energy supply in urban areas can be categorized in two approaches, short-term approach, the ability of coping with threats such as earthquakes, floods, etc., and long-term approach to deal with impacts of climate change and global warming on energy supply.
In this paper, using literature review, expert survey, and Fuzzy analytic hierarchy process (FAHP) method, the main criteria were categorized into four themes: technical and infrastructure, built environment, governance, and socio-cultural. The sub-criteria of each group were also prioritized in both approaches. In short-term approach, the sub-criteria with high priority in energy resiliency include energy storage system, urban development pattern and population density, education planning, participatory governance, and culture building and public awareness. In the long term, they include increasing energy efficiency through innovation, producing energy from renewable sources, mitigation methods of energy consumption in buildings, Regulatory basis and executive requirements, mechanisms for attracting private sector investment in low-carbon development, culture building and public awareness.
Also, by comparing the priorities in each sector, common influential factors in both perspectives were presented that can provide a suitable tool for managers to plan for the development of low carbon and resilient communities.

Keywords: Resiliency, Urban Energy, Criteria, FAHP, Energy management

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Introduction

Today, around 60 % of the world population lives in urban areas and this proportion is expected to increase in the coming decades. Over 70 % of the global energy is consumed in cities, and with the increase of urbanization rate, it is predicted that cities will be the main consumers of energy carriers in the future. Increasing consumption of energy in urban areas, can be considered as one of major driver of climate change and rising concentration of carbon dioxide in the atmosphere, which in turn can threatens the security of production, transmission and energy supply. Each of these threats have significant consequences on energy security for urban communities, and due to the close relationship between energy and water, food and health, the disruption of energy supply can cause difficulties for urban system performance. Therefore, energy resiliency in urban environment can be divided in two clusters, short - term such as earthquake, flooding, etc. and long-term in order to deal with negative impact on energy sector due to global warming and climate change. By reviewing the articles about frameworks and models of resiliency, it is noted that each of these models has developed a specific part of the energy resiliency .This comprehensive study has indicated the necessity of determining the effective factors in energy resiliency and their prioritization in order to develop an integrated model to evaluate and monitor urban energy resiliency.

Material and Method

In this study, the criteria extracted from literature review on urban resiliency in general and urban energy resiliency in particular, are divided into four categories, which include criteria related to technical and infrastructure, built environment, governance and socio-cultural. Using vast literature review, a list of effective factors including criteria and sub-criteria with mentioning their frequencies in scientific resources was obtained. Then, a questionnaire including a complete list of sub-criteria consisting of 34 factors was prepared.

The survey of experts, based on Delphi method, was conducted through questionnaire, which included 33 related faculty members, specialists and governmental managers in the field of energy. After receiving the answer, the results were recorded in SPSS statistical software and the reliability of the questionnaire was measured. A questionnaire was designed to assess the importance of each of the sub-criteria in urban energy resilience in two short-term and long-term approaches. On the next steps, the sub-criteria were prioritized in each of the four categories of technical and infrastructure, built environment, governance and socio-cultural by performing pairwise comparison and using fuzzy hierarchical analytical method (FAHP) in each approach individually.

Eventually, priorities of the four main criteria was surveyed using the paired comparison questionnaire with considering the sub-criteria of each part of the results of the previous stage, and the weight of the main criteria was obtained in two approaches using FAHP method.

Discussion of Results

According to the criteria extracted from literature review, considering their frequency in sources and surveys of experts, the following results were achieved from the analysis of data by FAHP method:

The complete list includes 34 sub-criteria, of which 13 sub-criteria are related to technical and infrastructure factors, 7 sub-criteria related to built environment factors, 11 sub-criteria related to governance factors and 3 sub-criteria related to socio-cultural factors. With the analysis of

each approach separately, the weight of sub-criteria and the priorities of each group were determined and some of the sub-criteria were removed due to its insignificance in each approach. In the short-term approach, in technical and infrastructure sector, energy storage systems have the highest priority, followed by fortification, diversification of energy carriers and distributed energy generation.

In built environment criteria, urban development pattern and population density have the highest priority. Other important items are reducing the energy footprint in water production, treatment and distribution. In governance, education and communication planning to raise public awareness, participatory governance, and scenario-based energy planning and risk management are high priorities. Culture building and public awareness of energy consumption management is an important sub-criteria in the socio-cultural sector. In the long-term approach, in technical and infrastructure criteria, increasing energy efficiency through innovation and technology is the highest importance, and energy production from renewable sources and energy intensity are other important factors in this sector.

Among the high priority criteria in built environment sector, the methods of reducing energy consumption in buildings, the diversity of transportation system and the methods of adaptation in buildings can be referred, respectively. In governance criteria, legislation and law enforcement, financial and non-financial mechanisms to attract private sector investment in low-carbon development are the highest priorities, followed by funding for research and technology development and energy pricing. In the socio-cultural sector, culture building and public awareness of energy consumption management is the most important sub-criteria in urban energy resilience, and then communal solutions to save energy can be effective in increasing resiliency. Comparing the obtained results in prioritizing the four main criteria, it is observed that in both short-term and long-term approach, governance, technical and infrastructure, built environment and socio- cultural criteria have high priority respectively.

Conclusion

Since in the short term, natural and man-made disasters and in the long term, the reduction of energy resources, and climate change can disrupt the functioning of energy supply as one of the important urban infrastructure, the issue of energy resiliency is very important in urban areas. At the beginning, research carried out in recent decades in the field of energy resilience was reviewed and the influential factors were divided into four categories: infrastructure and technology, built environment, governance, and socio-cultural. By expert's survey and fuzzy hierarchical analysis, the priorities of each criteria and Sub-criteria in both Short-term and long-term were identified, separately. It is observed that, the priorities of the sub-criteria in each category are different in both short-term and long-term approaches. The common high priority in both approaches is the education and culture building of energy consumption in socio-cultural criteria. Therefore, the importance of education and awareness in developing energy resiliency is evident.

There are also some common items in both approaches (with different priorities). In the technical and infrastructure criteria, energy production from renewable sources, distributed energy generation, diversity of energy supply, diversity of energy carriers and energy storage can be emphasized. This shows the importance of using renewable energy in the urban areas, because the use of renewable resources covers many resilience characteristics such as diversity, storage and distributed generation. In built environment criteria, all seven defined

sub-criteria are affected by different priorities. Priority in both approaches are to reduce energy consumption in the building and to diversify the transportation system. In the governance sector, all sub-criteria defined with different degrees of importance are effective, and the sub-criteria that is observed in both approaches of high importance is legislation and executive requirements. It is concluded the importance of developing and implementing laws in urban society to increase resilience.The research also has shown that, the four main criteria have almost the same priority in both approaches. In the next step by using the obtained prioritization, and quantifying each criterion, a composite index can be defined to evaluate the energy resiliency in the urban areas. The composite index allows comparing the resilience in different cities. Based on this index, the resilience of world cities can be compared in both short-term and long-term approaches. Therefore, conducting this research is the first step towards developing a comprehensive evaluation and management model of urban energy resiliency.