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Development of a general sustainability indicator for renewable energy systems: A review

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ABSTRACT

Renewable energy is considered as a solution for mitigating climate change and environmental pollution; however, an important problem of the application of renewable energy systems (RESs) is that the evaluation of the sustainability of these systems is extremely complex. In order to assess the sustainability of renewable energy systems comprehensively, the use of sustainability indicators (SIs) is often necessary. Since sustainability indicators are necessary to reflect various aspects of sustainability, the development of a general sustainability indicator (GSI) including many basic sustainability indicators (BSIs) becomes critical. In this paper, the methods of selection, quantification, evaluation and weighting of the basic indicators as well as the methods of GSI aggregation are reviewed. The advantages and disadvantages of each method are discussed. Based on these discussion and the analysis of the uncertainties of sustainability assessment, an effective framework and its procedures of the development of GSI for renewable energy systems is presented. This GSI is not only able to evaluate all the sustainability criteria of RESs, but also can provide numerical results of sustainability assessment for different objective systems. The proposed framework in this study can be used as a guidance of the development of sustainability indicator for various renewable energy systems.

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1. Introduction

In recent years, an increasing number of renewable energy sources such as geothermal, solar, wind, combustible renewables and waste are used over the world, because of their advantages of less emission, less pollution, clean and less fossil fuel resources usage. In order to guide future investment of a renewable energy source based system, the sustainability of the system should be assessed for decision-making; however, there is no common tool available to evaluate all the aspects of sustainability. For example, cost is only used to reflect the aspect of economic sustainability, but it is incapable of evaluating the system quality of other sustainability criteria like environmental and social considerations.

This paper aims to propose a development framework of a general sustainability indicator (GSI) for RESs through reviewing and comparing the different ways of indicator selection and indicator modeling strategy. This GSI is a tool of sustainability measurement reflecting all the criteria of sustainability assessment including economical, environmental and social criteria. Through investigating the disadvantages of the development methodology of existing sustainability indicators, the fuzzy analytical hierarchy processing (FAHP) and fuzzy comprehensive evaluation (FCE) methods are employed to aggregate all the selected basic indicators and criteria into the general indicator.

2. Concepts of sustainability indicator

Sustainability indicator for RESs is developed to measure sustainability reliably. The main objective of SI is to provide a comprehensive and highly scalable information-driven architecture of sustainability assessment [1]. Most existing SIs are quantitative, so that it is understandable who is considering of a renewable energy system's sustainability and who will help them to make a decision on the investment [2]. A few basic types of SI

can be distinguished by their methods of construction and level of aggregation [1], as outlined below:

- Indicator: This includes results from the processing (to various extents) and interpretation of primary data.
- Aggregated indicator: This combines, usually by an additive aggregation method, a number of components (data or sub-indicators) defined in the same units.
- Composite indicator: This combines various aspects of a given phenomenon, based on a sometimes complex concept, into a single number with a common unit.
- Index: This generally takes the form of a single dimensionless number. Indices mostly require the transformation of data measured in different units to produce a single number.

The GSI of this study is the fourth type (index), because it has to reflect all the aspects of the sustainability quality of a whole renewable energy system, as well as the interaction of its sub-systems and/or components [3] and, more importantly, all the quality parameters have different units. As a result, the main challenge of SI development is to assess the various criteria of sustainability, and if a single criterion is used to assess the system's sustainability it does not work any more. An example is taken to present this issue. The mean cost of electricity generation of solar PV (photovoltaic) and wind energy is respectively up to 0.24 and 0.07\$/kWh, while the conventional coal electricity generation just costs 0.048\$/kWh. This means that coal electricity is better than solar and wind economically, but this does not mean that coal is better than the other two energies when seen from other points of view.

As discussed above, the hierarchy of this GSI has to have three levels as shown in Fig. 1. The top level is called the general sustainability indicator (GSI) [4–6]. This level gives a numerical evaluation of the sustainability. The second level is the criteria (C_i) level. This level generally includes a few assessment criteria of

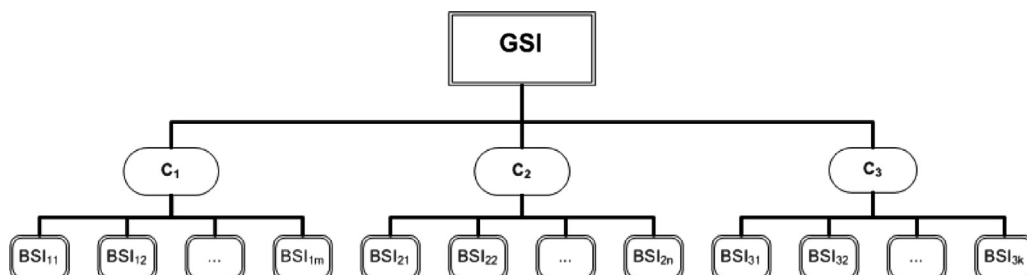


Fig. 1. The hierarchy of GSI.

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