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Multi-source energy systems analysis using a multi-criteria decision aid methodology

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ABSTRACT

In this article, an original multi-criteria approach is applied to multi-source systems used for the design and the choice of the optimal alternative. The high number of alternatives and potential solutions when dealing with multi-source systems require a decision support method to be implemented and easy to use. Information data on the economic variables, energy performance and impact on the environment of the systems are presently data which analysis and quantification is difficult. To deal with this high level of complexity and uncertainty, an evaluation approach is needed. The multi-criteria decision support methodology concept is described (ELECTRE III) and then applied for a case study. The decision support algorithm has its bases on the developed models and makes the outranking of possible solutions. It is also shown that multi-criteria analysis can provide a technical–scientific decision-making support that is capable to justify the clearly rank of the alternatives in the renewable energy sector. The use of multi-criteria decision aid for assessing the multi-source systems showed encouraging results and interesting insights.

1. Introduction

The building sector - i.e. residential and commercial buildings - is the largest user of energy and CO_2 emitter in the EU and is the major energy consumer of the EU's total final energy consumption and CO_2 emissions. Buildings account for 40–45% of energy consumption in Europe and China (and about 30–40% world-wide) [1]. Buildings are important consumers of energy and thus important contributors to the emission of pollutants into the atmosphere.

The development and integration of appropriate renewable energy technologies in buildings has an important role to play. However, issues of cost, investment and ownership along with technical risk provide disincentives to the uptake of embedded energy technologies.

The main issues of renewable energy sources large-scale use are related to the sizing of the systems, the choice among a large variety of alternatives face to a certain number of criteria, and finally the control of these sources. In the near future, more and more the renewable energy sources (RES) will cohabit with fossil energy source systems and research has to be pointed toward solutions that are energy efficiently, economical viable and environmental friendly. The goal of a multi-source system is to decrease at maximum the primary energy consumption by generating the needed demand by renewable sources like solar, wind or wood energy.

The RES can be easily adapted and linked with conventional modern energy technologies to ensure security of supply at all times and at any location. A massive use of RES will not be a sustainable solution except if it is complemented with a valid evolution of the economic development pattern and through European directives. Moreover, it will be highly influenced by the fiscal measures like carbon tax and financial aids. The challenge of sustainability with regard to energy is shaped and the requirement for green sources has been established, but still a number of barriers need to be overcome before the contribution of RES becomes significant.

In a management process of RES with classic fossil sources a number of processes should be considered by the decision makers, such as energy production, conversion and transmission. Furthermore, RES are subjected to uncertainties of economic and environmental implications. Therefore, effective planning for RES management systems under multiple uncertainties and dynamic complexities is desired.

The RES will produce locally the energy needed for the building and the extra energy which is not necessary will be sent to the overall urban energy infrastructure (i.e. the case of photovoltaic power energy or wind energy). An example of multi-source system is between a solar thermal system used to produce domestic hot water, a photovoltaic system to generate electricity and a gas boiler heating system for the heating energy demand. Other examples can

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imply a wood boiler for the heating or an electric energy heating system.

2. Decision-aid approach for multi-source systems

2.1. Framework

The high number of alternatives and potential solutions when dealing with multi-source systems require a decision support method to be implemented. Information data on the economic variables, energy performance and impact on the environment of the systems is presently affected by vagueness. To deal with this high level of complexity and uncertainty an evaluation support approach is needed. Multi-criteria decision aid methods provide an approach that is able to handle a large amount of variables and alternatives assessed in various ways and consequently offer valuable assistance to the decision maker in mapping out the problem. The multi-criteria decision aid (MCDA) do not replace the decision makers, but rather support them in all the stages of the decision making process by providing useful data information to achieve decisions that are clear.

A typical MCDA problem consists of a given decision matrix, with n number of alternatives and j number of criteria (i.e. payback time). Additionally, a set of weighting factors p_j is introduced to represent the relative significance of criteria in a particular application. Moreover, different thresholds may be required to represent the preference, indifference or veto of the criterion. The final goal of MCDA is to classify and/or rank the alternatives. One of the most complex MCDA is the ELECTRE III approach; the method is based on a well-developed multi-criteria analysis model, which takes into account the uncertainty and fuzziness, which are usually intrinsic in data obtained by predictions and evaluations.

The use of multi-criteria decision has become lately of high interest for various researchers: Cavallaro [2] used it to assess concentrated solar thermal technologies; Papadopoulos et al. [3] applied the multi-criteria analysis method ELECTRE III for the optimization of decentralized energy systems. A modeling approach to multi-energy systems in buildings based on the concept of hybrid energy hub is presented by Corrado et al. [4]. Using the same concept of energy hub, Fabrizio [5–8] has studied different systems, with the aim of selection of energy source to be adopted and the optimum operation strategies. The MCDA methods used in the present article research work use a modeling activity, which should make clear many aspects, making the decision progression more transparent.

2.2. Multi-source systems

The multi-energy source buildings have been lately extensively studied from different researchers due to their potential to reduce the building energy consumption and to eventually arrive to a zero or even a positive energy building. The objective of multi-energy systems is to reduce the primary energy consumption by producing the needed energy directly on site.

Starting to the point that a renewable energy system is implemented in a building we can speak of a multi-energy source building. Several examples of multi-source building studies are found in the literature, Trillat-Berdal et al. [9] studied the couple solar thermal panels-geothermal heat pump by an extended experimental and simulation campaign. Sontag et al. [10] analyzed the combined cogeneration with solar energy (thermal and photovoltaic) with the wind energy. The advantages of having multiple sources of energy on the same construction are different from case to case (i.e. for certain climate areas installing solar thermal panels is not economic rentable but a geothermal heat pump will be a good decision).

In this context of multi-energy systems an important but in the same time difficult task would be to identify the alternative (multi-source system configuration) that minimize the energy consumption and the investment payback time. The research work of this article and the main objective is concerned with the means to make informed decisions in renewable energy strategies and the use of multi-source systems.

A number of energy systems were detailed from the sizing study to the ecological or economical impact.

The studied systems are:

- Solar thermal system (ST)
- Solar photovoltaic system (SP)
- Wood boiler heating system (WB)
- Geothermal heat pump system (GHP) - horizontal and vertical borehole heat exchangers
- Gas boiler heating system (CGH)

In all the further analysis the electric energy is assumed to be the reference energy; the reference heating system is based on electric convectors and the renewable energy heating systems are compared to this system. It will be considered that no more than one heating system is installed on the building (alternative wood boiler + geothermal heat pump is not considered). For the ST and SP systems, six solutions for each of them will be analyzed; one reference and five other alternatives where different system parameters are changed, like system costs, panel area, thermal proprieties, slope, etc. Each of these cases (six for the ST and six for the SP) is coupled with a single heating system (i.e. wood boiler heating system) (see Fig. 1). A total number of 144 coupling multi-source systems are possible, like shown in the diagram.

The systems presented have their particularities, their costs, environmental potential and lifetimes but the high number of possibilities and the parameters to analyze and to rank require the necessity of a methodology and complex calculations. This high level of complexity was solved by developing an own software called ECO-Sol and which allowed fast calculations and scenario studies, during the whole process.

2.3. ELECTRE III decision analysis

The outranking relation concepts and methods were established by Roy which initiated and developed the ELECTRE (ELimination Et Choix Traduisant la REalite/Elimination and Choice Expressing the Reality) outranking approach models [11]. This method has been

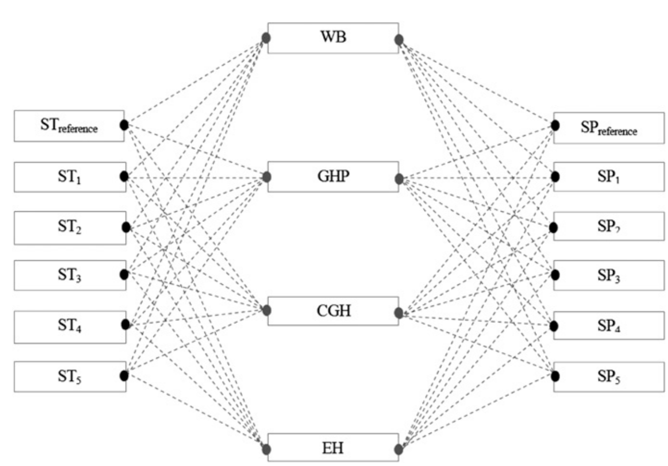

Fig. 1. Diagram of possible connections for a multi-source energy system.