A MATHEMATICAL MODEL FOR STRATEGIC INVESTMENT IN RENEWABLE ENERGY

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Abstract - Countries around the world have explored energy alternatives by taking advantage of new technologies and in response to increasing energy demand. Investments on renewable energy has been increasing for the last decades. Strategic decisions such as new facilities for renewable energy applications require integration of a large amount of data and detailed modeling and analysis. This research develops a mathematical model that helps determining the investment in renewable energy facilities under certain constraints such as budget, environmental impact and maximum capacity. The solutions of the proposed model supports strategic decision making for renewable energy.

I. INTRODUCTION

Energy consumption has accelerated because of rapid economic development and increase of the world population [1].Governments and private investors have diversified investment in various energy alternatives. Since the 1980s, carbon emissions and environmental awareness have pushed more investment toward renewable energy. Countries that depend on imported fossil fuel face great uncertainties in the supply, price, and transportation of oil; historical and potential energy crises have encouraged governments to make strategic renewable energy investments [2].Renewable energy has long-term environmental benefits, and requires detailed planning before major investment with respect to cost (e.g., operating and maintenance cost),affordability (e.g., maximum production capacity and breakeven point), environmental impact (e.g., carbon emission and effects on wildlife), job creation, and security (e.g., regulations and emergency response).

In previous studies, many methods such as Multi-Criteria Decision Method (MCDM), Cost-Benefit Analysis (CBA), Life- Cycle Analysis (LCA), Strengths, Weaknesses, Opportunities, and Threats (SWOT), Delphi, and checklists were usedin the analysis ofenergy investments. The aim of this study is to build a mathematical model to find optimal investment strategies for renewable energy in cities of interest.Solutions to the mathematical model indicates how investments may be allocated among different types of renewable energy for a particular city in consideration of available budget, maximum efficiency, environmental impact, feasibility, job creation, and security.

II. RELATED RESEARCH

To the best of authors' knowledge, there are five studies [3, 6, 10, 15, and 18] that are directly related to investment strategies for renewable energy. Boie et al.(2013) [3] studied energy strategies for nine regions in Europe. The paper investigated increasing negative effect of the CO_2emission on the climate, and renewable and clean energy investment decisions that can reduce the negative effect on the climate [4]. The SUSPLAN was selected as a methodology and the nine regions in Europe were used as application areas. The study determined the regions that were suitable for each type of renewable energy [5]. Boie et al.(2013) [3] also concluded that the development of technology and financial constraints must be considered in making decisions about investment in renewable energy. Ek (2002) [6] investigated the increasing use of renewable energy resources to meet energy needs,external costs of renewable energy, and its positive effect on the nature by reducing carbon emission. The choice experiment [7] and SPSS analyses were used evaluate the attributes of renewable energy alternatives. This study [6] concluded that benefits of renewable energy alternatives, their regional impact on job opportunities, public acceptance, and cost [8] should be considered in making investments in renewable energy.

Energy needs are expected to increase for the near future and are driving governments around the world to seek new energy alternatives[9]. Several oil crises had occurred in the past [10] and strategic investment decisions on renewable energy alternatives are critical [11].Three methods [10], including the LCA [12], CBA [13], and Multi-Criteria Decision Aid (MCDA) [14], were used to determine the trend of investments in renewable energy. The LCA analyzes the environmental impact and investments over the entire life of a renewable energy alternative and calculates the amount of energy and materials consumption and wastes releasedinto the environment [12]. The CBA comparesinvestment costs and benefits of energy alternatives [13]. The MCDA is widely used to evaluate energy investments [14].

As an example of investments in renewable energy, wind farms and wind energy supply have increased

significantly in China [15]. This increase affected electricity prices and strongly suggests that it is necessary to conduct feasibility studies for investments in renewable energy [16]. In addition to aforementioned methods, some other analytical tools such as Analytical Hierarchy Process (AHP) and Benefits-Opportunities-Cost-Risks (BOCR) may be used to help make investment decisions [17]. Guerrero-Liquetet al. (2015) [18] used Delphi, checklist, SWOT, and AHP methodsto analyze risks for solar energy investments in Dominican Republic. Benefits of renewable energy are abundant and include wealth creation, employment, and new job opportunities [18].

The rest of this article is organized as follows. Section 3 describes the mathematical model, including decision variables, objective function, constraints, and parameters. Section 4 discusses how model parameters are determined and the implications of model results. Section 5 concludes the article with future research.

III. MATHEMATICAL MODEL

There are two sets “i" and “j” in the mathematical mode. “i"is the index of criteria for the assessment of renewable energy alternatives (where $E, M \in j$) and j is the index of renewable energy alternatives. W_i is a parameter and is the importance of criterion “i". P_{ij} is a parameter and is the performance score for alternative j with respect to criterion i. B is a parameter and is the available budget. In this section, mathematical model and its components are displayed. Criteria are symbolized by “j” and those are the aspects that affect the decision. Alternatives are symbolized by “i”and it shows the possible renewable energy resources in the generalized mathematical model. The importance levels of each criterion are shown as “W_i”. “Pij” symbolizes performance level of i^{th} alternative and j^{th} criterion. “B” is the budget and c_j is the cost of j^{th} renewable energy resources’ cost. “ETH” and “MTH” are the thresholds for environmental impact and maximum capacity for the city. “H” and “L” are the minimum and maximum number of plant that can be built in the particular cities. x_j equals to “1” if j^{th} alternative is implemented and “0” in other cases.

$$\max \sum_{i=1}^{I}\sum_{j=1}^{J} W_i * P_{ij} * x_j \quad (1)$$

subject to

$$B \geq \sum_{j=1}^{J} x_j * c_j \quad (2)$$

$$E\,TH \geq x_j * P_{Ej} \quad \forall j \quad (3)$$

$$M\,TH \leq \sum_{j=1}^{J} x_j * P_{Mj} \quad (4)$$

$$H \geq \sum_{j=1}^{J} x_j \geq L \quad (5)$$

$$xj \in \{0,1\} \quad (6)$$

Equation(1) provides the maximum sum of the weighted performances. Equation (2) prevents the budget to be exceeded in line with the investments made. Equation (3) ensures that the energy type remains below the environmental impact threshold defined by the city, if a renewable energy investment is made. Equation (4) ensures the total production of the installed facilities is higher than the need of the city. Equation (5) means that the number of facilities to be established is within the range allowed by the city. Equation (6) is the definition of the variable.

Obtaining Sets and Parameters and Solution Implications of the Proposed Model

The criteria should be determined with the opinions of the experts and the questionnaires and from the existing literature.The renewable energy alternatives should be defined by the experts’ opinions and questionnaires for the concerned city and only the possible ones should be taken as alternatives.

W_i weights parameter should be calculated by the experts’ opinions using the AHP, VIKOR, ELECTRE, orTOPSIS.The performance values (P_{ij}) can be determined by the experts. To achieve this, Delphi method, Surveys, Data Envelopment Analysis, and Point Allocation may be used.The budget of the city should be statedby whom is going to make the investment (government, private sector).The cost of each facility (C_j) should be calculated.Minimum and maximum expectations (ETH and MTH) should be investigated according to the regulations of the city.Number of minimum and maximum facilities (L and M) that have to be built in a city.

After obtaining the parameters, the model can be run and the model solutions derives that which type of energy plants should be built in the concerned city where the total impact and manufacturing capacity thresholds are also achieved under the certain amount of budget.

CONCLUSION

The importance of obtaining optimal strategic and feasible solutions when investing in renewable energy is increasing and various methods can be used in making these decisions. This proposed mathematical method may be used to find the best investment strategies for renewable energy.

In future works, this model is intended to be used with the help of the methods mentioned in the previous section. After the implementation of the

model, interviews with decision-makers will be conducted,and the ability of the model to meet the needs will be measured and sections to be developed will be determined. As a result of these interviews, the scope of the mathematical model will be expanded. For example, goal programming can be used since the thresholds can be taken as target values. After the development and expansion of the mathematical model, this model can be made available not only for strategic renewable energy alternative investment decisions but also for all energy alternative investments.

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