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Model of sustainable development of energy system, case of Hamedan

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ABSTRACT

Sustainable economic growth and improvement of the social welfare depend upon the sufficient supply of energy resources, while the utilization of energy resources is one of the main factors of environmental degradation. This research is involved with development of a sustainable energy system model and a new method for sustainability assessment. This model represents the flow of energy from primary resources through processing, conversion, and end-use technologies in an optimization framework where the useful energy demand in various social and economic sectors is met. The impact of energy supply and consumption chain on the environment at each level of energy system is also embedded in the model structure. A multi-criteria analysis of changes is then applied and sustainable development indices of the whole system are concluded. Finally, effects of the energy subsidy policy and high economic growth rate on sustainability of the energy system in three scenarios are analyzed. Results demonstrate that energy subsidy decelerates the improvement rate of the total sustainability index. Also, when a high economic growth is accompanied with the energy subsidy this index reduces considerably. Results show that how penetration of renewable energy potentials changes the sustainability situation of energy systems.

1. Introduction

Over-exploitation of exhaustible energy resources along with the destruction caused by human activities in recent decades have caused the different environmental degradations. Therefore, the utilization of natural resources would be imperiled. Consequently, the life of human kind will be exposed to severe difficulties. Sustainable development of energy system is a way in which the processes of industrial and socioeconomic development should be compatible with the environment. In the sustainable development literature, the environment is considered as a form of natural capital. It should be noted that “it is not always possible to substitute human-made capital for natural capital” (Faucheux, 2002), since the natural capital is the life-supporting form of capital. Hence, the natural capital is basically more crucial and important rather than human-made capital (Faucheux, 2002).

The main concern of experts in the sustainable development area is about developing communities. Because, the main goal in most of these communities is only socioeconomic development. Furthermore, protection of the environment is not a priority and it is considered as an obstacle on the path of development. It has indicated that in developing countries (with Gross Domestic Product below 20,000$) raising of GDP results in an increasing rate of CO_2 emission. In contrast, developed countries direct their efforts for achieving to a low carbon society (Kohko and Keigo, 2011; Yale Center for Environmental Law and Policy, 2010). The sustainable energy system is obtained by making policies with respect to the sustainability aspects: economic, social and environmental. If sustainability is a systematic target, it will necessary to provide a tool that measures whether a decision or policy is moving towards sustainability (Hiremath et al., 2013). However, providing efficient and reliable tools has posed serious challenges for scientific community.

1.1. Sustainability assessment

Sustainability assessment of energy system is a tool that informs policymakers about the options they have, and sustainability indicators can play a major role in evaluation of various options. Defining a set of sustainability indicators is a crucial step in sustainability assessment. It should be noted that energy indicators are not just statistics about energy systems. Usage of these indicators results in a more profound understanding about the interactions among the energy, environment, and socioeconomic sectors (Ivan and Lucille, 2007). Evaluation of sustainable development depends upon the combination of defined indicators in three aspects: economic, social, and environmental (OECD, 2005). Investigation of the relationships among the energy, socioeconomic and environmental systems by indicators yields more deeply system analysis. Because, they are interwoven in a complex system. Thus, activities in any system would have unavoidable direct

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and indirect impacts on the others. The changes of energy indicators during time can be interpreted as closeness to energy sustainability (Ivan and Lucille, 2007).

One classification of sustainability assessment tools is to group them into three categories: 1) Indicators and Indices, 2) Product-related assessment and 3) Integrated assessment (Ness et al., 2007).

Tools in the first category are the easiest and most common tools that quantitatively monitor the sustainability of an energy system. These tools can further be broken down into integrated and non-integrated. Sustainable national income, environmental sustainability index, and ecological footprint are the most common samples of integrated indices that are employed by integrated tools of the first category. Although most of sustainability assessment studies employ the first category tools, particularly non-integrated indicators, these tools are not able to consider interactions among the sustainability aspects simultaneously. They also have a retrospective viewpoint and are appropriate only for short-term predictions (Ness et al., 2007).

The main concentration of second category tools, which focus on production processes, is to evaluate different flows of energy and material in relation to the products. They aim to identify particular risks and inefficiencies to support decision-making process. These tools are more preferred for the life cycle assessment of a product rather than analyzing a complex system. In addition, their focus is on the environmental aspect of sustainability (Ness et al., 2007).

Tools of the third category meet a large number of important topics in the sustainability area, and against the first category they have an ex-ante viewpoint. These tools often are based upon the system analysis approach and the consideration of social and environmental impacts. They include the conceptual modelling, system dynamics, multi criteria decision-making and the analysis of risk, uncertainty, vulnerability and cost-benefit. Multi criteria decision analysis (MCDA) is one of the most effective methods, which can simultaneously consider all sustainability facets. Moreover, it can employ both qualitative and quantitative indicators (Ness et al., 2007).

Although the employment of third category tools provide the comparison and evaluation of different choices, these tools cannot explain how a system is evolved and optimized during time. Hence, the incorporation of an optimization framework for sustainability assessment promotes the quality of evaluations. In this way, it is possible to assessment the sustainability of optimum points of energy system under various policies and conditions. However, most of prospective studies often assess the sustainability of energy systems based upon a set of predetermined decisions in target year. So that, neither the energy supply chain is optimized nor variable changes of middle years are specified (see Table 1). Therefore, it cannot be tracked the evolution of the energy system and managed the decision support system in these years.

This paper is involved with development of sustainable energy system model (SESM) and employing a new method for sustainability assessment of it. In this method, the energy system is optimized considering economical and environmental factors. Thus, the optimum trend of the system development and evolvement is specified. Then, a set of sustainability indicators in three dimensions of sustainable development is defined. These indicators are weighted by analytic hierarchy process (AHP), and the sustainability assessment of the optimized energy system is accomplished by MCDA. Finally, this paper analyses effects of the energy subsidy policy and high economic growth rate on the sustainability of the case of Hamedan.

1.2. Case of Hamedan energy system

Hamedan province with a population more than 1,900,000 is located in the west of Iran. Primary energy of hamedan energy system (HES) is mainly constituted by fuel imports (see Fig. 1). Main energy carriers utilized in Hamedan are natural gas ($2.470 \times 10^9 m^3$ annual) and petroleum products (12.01 Mboe annual). In addition, 99.9% of electricity comes from burning of furnace oil and natural gas in a steam power plant and the rest from a small hydro power plant (Power Administration of Iran, 2013). Final energy supplied for end-use and power production sectors has shown in Table 2. In this study five end-use sectors for Hamedan are considered: household (Hh), commercial and public (C & P), industry (Ind), transportation (Tra) and agriculture (Agr)). Because of a high dependency on fuel imports only a small number of processing units have been founded in HES. Hence, the most energy wastes occurs in end-use sectors and the steam power plant. Burning of fossil fuels caused to large emissions of carbon dioxide, methane and air pollutants (see Table 3). Moreover, the electricity generation has brought about too problems for agriculture and residential sectors due to over-exploitation of underground water beds. However, employing of regional and renewable energy potentials in an optimization framework can reduce the high dependency on fuel imports and large emissions.

Social issues of the energy sustainability is an important area which particularly focused on in recent decades. The square distribution of energy carriers, the energy cost of households and health concerns of energy systems are of most important issues that followed in the social aspect of energy sustainability. Hamedan with electricity coverage for 98.5% of population, natural gas coverage for 88.9% and full coverage of other critical fuels has possessed a good situation of energy equity issues. Also because of governmental energy subsidy, households spend only 3.47% of their incomes to comply their energy needs (e.g. gasoline, electricity, natural gas, etc.) (Statistical center of Iran, 2013). While if these subsidies have not paid, it would approach to 13.5% (for same final consumption and income) (Statistical center of Iran, 2013). Annually, 24.8 people per 100,000 lose their lives in the transportation system of Hamedan whereas in many developed countries it is 3–7 fatalities. Thus, transition from private road transportation to the rail and air systems promotes the health situation of HES.

2. Methodology

The methodology of this work for sustainability assessment of HES includes six following steps.

Step1: The conceptual model of the energy system as the initial conceptualization mechanism of a large computer model is developed to depict fundamental relationships among the stocks, flows, technologies and different levels of the energy system.
Step 2: Based upon the conceptual model, SESM is developed, which in more than 380 technologies by employing of 50 energy carriers is modeled. Parameters that examined and compared in SESM are: cost issues, capacity factor, efficiency, load zones, operation modes (more than 480), physical limitations and environmental destructions. The objective function of SESM is minimization of total costs (Z) that encompasses five terms (see Eq. (1)).

$$Min\ Cost\ Z = C + M + O + R + E \tag{1}$$

where C, M, O and E respectively represent capital, maintenance, operation and externality costs and R refers to opportunity cost of resources.

Step 3: SESM specifies the optimum equilibrium point of energy demand and supply. In general, three main groups of results is obtained by execution of the model.

In the first group, SESM outputs information about the values of primary, secondary and final energy flows and employed capacities at all levels of the energy system, each time and each load zone. In the second group, it specifies infrastructural developments and alternations, costs and investments at each time point. Impacts of the energy system on the environment are put into the third group of results. These impacts include carbon dioxide (CO_2), carbon monoxide (CO),