Energy Policy 87 (2015) 447–454

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Multi-criteria model for sustainable development using goal programming applied to the United Arab Emirates

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HIGHLIGHTS

- Multi-criteria model for achieving sustainability goals by year 2030.
- Integrates criteria on electricity, GDP, GHG emissions for optimal labor allocation.
- Future electricity demand requires contribution from renewable sources
- Enables planning for long term investments towards energy sustainability.

ARTICLE INFO

Article history:
Received 13 May 2015
Received in revised form
18 September 2015
Accepted 21 September 2015

Keywords:
Sustainability
Multi-criteria analysis
Weighted goal programming model
Energy consumption
GHG emissions

ABSTRACT

Sustainable development requires implementing suitable policies integrating several competing objectives on economic, environmental, energy and social criteria. Multi-Criteria Decision Analysis (MCDA) using goal programming is a popular and widely used technique to study decision problems in the face of multiple conflicting objectives. MCDA assists policy makers by providing clarity in choosing between alternatives for strategic planning and investments. In this paper, we propose a weighted goal programming model that integrates efficient allocation of resources to simultaneously achieve sustainability related goals on GDP growth, electricity consumption and GHG emissions. We validate the model with application to key economic sectors of the United Arab Emirates to achieve sustainable development goals by the year 2030. The model solution provides a quantitative justification and a basis for comparison in planning future energy requirements and an indispensable requirement to include renewable sources to satisfy long-term energy requirements.

1. Introduction

The rapid economic growth combined with increasing energy demand and its impact on environment has increased the focus of global nations for sustainability efforts. To achieve sustainable development goals, countries need to focus on developing suitable policies that jointly address efficient energy consumption, improved economic development, and reduced greenhouse gas (GHG) emissions. Over the recent decades there is a growing concern about the increasing GHG emissions harmfully affecting our living environment that requires timely intervention and a shared sense of responsibility in reducing emissions to adequate levels. The Kyoto Protocol (1997) provides a suitable framework and differentiated accountability among developed and developing nations to implement optimal control strategies for reducing GHG emissions. Tough developing countries are keen on reducing their contribution of GHG emissions, it contradicts their own agenda for economic and labor growth. Several studies have established the role of rapid population growth, urbanization and energy consumption which have led to increased levels of GHG emissions (Shahbaz and Lean, 2012; Kaygusuz, 2012). Between the years 1990 and 2010 the world population growth was approximately 30%, or 1.6 billion people. The growing demographic trend has led to increased energy consumption contributing to GHG emissions. Today energy sector alone accounts for more than two thirds of the GHG emissions with more than 80% of the global energy needs are satisfied using hydrocarbon- based sources.

The interplay between energy consumption, environmental responsibility and economic development is crucial to the success

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http://dx.doi.org/10.1016/j.enpol.2015.09.027
0301-4215/

of any sustainability efforts. Despite international efforts GHG emissions are larger today and are accumulating at an accelerating pace. Controlling and mitigating energy related carbon emissions requires timely governmental intervention integrating conflicting objectives on economic development, energy consumption, population demographics and environment. In this paper we develop a goal programming (GP) model based on input–output model that integrates efficient allocation of resources (labor) to achieve sustainability related goals on economy (GDP), energy (electricity consumption), and environment (GHG emissions) applied to the key economic sectors of United Arab Emirates (UAE) to achieve sustainability related goals by the year 2030. The results can be used for studying trade-offs involved in resource allocation among the different economic sectors, channeling long term investments towards energy sustainability and provide a quantitative basis for policy planning and regulation.

The UAE is the 10th largest oil producing country in the world with a high GDP per capita. Since its independence in the year 1971, the UAE has undergone rapid economic growth and overall development. Such development has led to a remarkable rise in energy consumption and a growing responsibility towards environmental protection. Situated in the Persian Gulf, the country experiences harsh climatic conditions for most periods of the year. Mokri et al. (2013) highlight the electricity demand in the UAE has increased from 38.6 TWh in the year 2000 to 90.6 TWh in 2010, with an average annual growth rate of about 8.8% during the last decade. Between 2006 and 2011, the annual increase in electricity demand (10.8%) has closely followed the trend of an 11% annual population growth rate (Mokri et al., 2013). Two important sources of the increased energy consumption and GHG emissions are due to electricity generation and water desalination. Currently, 97.5% of electricity generation in the UAE is based on natural gas-powered plants (Omri, 2013) leading to an increased production of GHG emissions including CO_2, SO_2, and other particulate matter. Due to very limited ground water potential, majority of water requirements for the growing population are predominantly met through desalination. DeFelice and Gibson (2013) elaborated the role of water desalination plants and its significance on energy consumption and air pollution. The CO_2 emission levels in the UAE have increased from 60.8 Mt in 1990 to 146.9 Mt in 2008 (Kazim, 2007; Qader, 2009). Omri (2013) indicate that Middle East and North Africa (MENA) region is the second most polluted region in the world, with highest CO_2 levels per dollar of output. According to the United Nations Framework Convention on Climate Change data, the UAE's total GHG emissions in the year 2000 were estimated at 128.3 Mt of CO_2 equivalent. This figure reflects a 64% increase in total GHG emissions since the year 1994. The UAE population constitutes a diverse mix of nationalities and cultures; over 80% of the population is expatriates or non-UAE nationals, and the labor market is heavily dependent on expatriates for the development and future growth. When comparing the average annual percent change in population, the UAE is currently in the top 10 countries in the world for population growth, and the estimated population of the UAE in the year 2013 was 9.34 million. It is very significant that to meet long-term sustainability goals, the top priority will emphasize reduction in the use of fossil fuel for electricity generation. Fig. 1 represents the trends in GDP, CO_2 emission and net electricity consumption in the UAE.

In this paper we extend the GP model developed in Jayaraman et al. (2015a) to explore potential trade-offs among the objectives (GDP growth, electricity consumption, and resource allocation) with the possibility of increasing GHG emissions and its relative impact on energy planning for long-term sustainability. The GP model provides the ideal framework that a decision maker (DM) can use to obtain optimal solution for problems with multiple competing objectives to plan and prioritize resource allocations.

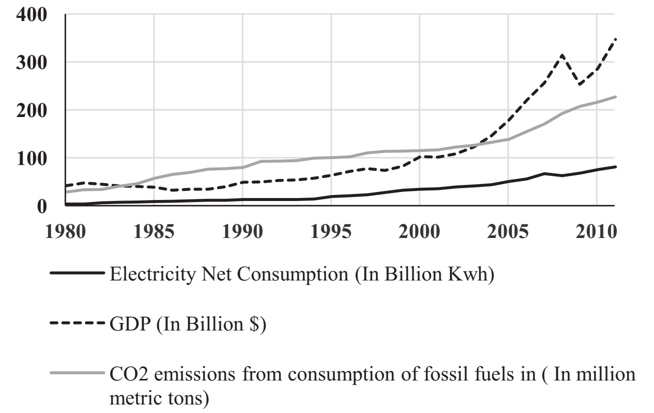

Fig. 1. Net electricity consumption, GDP growth and CO_2 emissions from fossil fuels in the UAE (Data Source: US Energy Information Association & World Bank).

The rest of the paper is organized as follows; in the next section we present a brief overview of Multi-Criteria Decision Analysis using GP, review related literature on GP models applied to energy and the environment, discuss data preparation and analysis, and model formulation and constraints. In Section 3 we discuss the results, and present the conclusions and recommendations for policy planning in Section 4.

2. Methods

2.1. Multi-criteria decision analysis and goal programming

Multi-Criteria Decision Making (MCDM) or Multiple-Criteria Decision Analysis (MCDA) is a discipline dealing with decision-making with multiple and conflicting criteria, objectives or attributes. Considering multiple criteria explicitly leads to more informed and better decisions. However, typically there is no unique optimal solution and therefore it is necessary to use the decision maker's preferences to differentiate between possible solutions and determine the best compromise. Many important advances have been developed in this field since the start of the modern MCDM discipline in the early 1960s, including new approaches, innovative methods, and sophisticated computational algorithms. The GP model is a well-known aggregating methodology for solving multi-objective programming decision aid processes. The GP model uses a distance metric to minimize the deviations between achievement and aspirational (goal) levels of each model criteria. In fact, both positive and negative deviations from the anticipated goals are unwanted. GP model was introduced by Charnes et al. (1952, 1955) with applications in various fields, such as accounting, financial portfolio management, marketing, quality control, human resources, production and operations management (Aouni et al., 2010a, 2010b, 2012a, 2012b, 2012c). Colapinto et al. (2015) present a state of art survey on multi-criteria decision analysis using goal programming with several applications in engineering, management and social sciences.

The general formulation of a MCDM model can be described as: Given a set of "p" criteria $f_1(x), f_2(x), \ldots, f_p(x)$, we optimize the vector $[f_1(x), f_2(x), \ldots, f_p(x)]$ under the condition that $x \in D \subseteq R^n$, where D designates the set of feasible solutions. Defining a vector function $f(x) = [f_1(x), f_2(x), \ldots, f_p(x)]$, a classical multi-criteria decision problem can be formulated as (assuming that all objectives have to be minimized):