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A Weighted Goal Programming model for planning sustainable development applied to Gulf Cooperation Council Countries

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HIGHLIGHTS

- Application of multi-criteria optimization model for sustainable development.
- GHG emissions targets cannot be attainable due to reliance on hydrocarbon sources.
- Provides quantitative evidence for future investments in green energy.
- Application to Gulf Cooperation Countries.

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ABSTRACT

The United Nations agenda for sustainable development by the year 2030 proposes 17 sustainable development goals which include access to affordable, reliable and clean energy, sustained economic growth with full productive employment and, urgent action to mitigate environmental degradation. Planning for sustainable development requires integrating conflicting criteria on economy, energy, environment and social aspects. In this paper, we introduce a Weighted Goal Programming model involving criteria on the economic development (GDP), the electricity consumption, the greenhouse gas emissions, and the total number of employees to determine optimal labor allocation across various economic sectors. The proposed model is validated with data from the six members of the Gulf Cooperation Council (namely Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates). The results of the model aim to provide empirical evidence and insights to decision makers and policy analysts in developing optimal strategies able to simultaneously satisfy energy demand, economic growth, labor development and reduction in greenhouse gas emissions to achieve sustainability targets by the year 2030.

1. Introduction

The rapid economic development in recent decades of the six member Gulf Cooperation Council (GCC, comprising Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) has brought significant challenges due to increased energy consumption and the environmental impact associated with greenhouse gas (GHG) emissions. The GCC countries together represent over one-third of world's oil and one fourth of natural gas reserves and have a pivotal role in the energy supply chain. Time-limited oil production, price volatility and other critical market factors present economic diversification as a key strategy in planning for sustainable development [1].

Economic growth, rise in population, increase in transportation, industrialization and, workforce expansion have strong interconnections with the increase in GHG levels. Economic growth encourages industrialization, boosts purchasing power and the demand for new goods and services, thereby increasing logistics and transportation. In turn economic growth also improves living standards, age and fertility, resulting in population growth. These together result in a nonlinear increase in energy consumption, which in turn contributes to the growing GHG emissions. The fast-tracked economic development of GCC countries has put incremental challenges on labor demand, development and infrastructure projects, electricity consumption, and GHG emissions to be addressed

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through strong policy alternatives for achieving sustainable development. The energy production is feared to fall short of the anticipated demand unless the energy portfolio is altered. Currently majority of the electricity generation in GCC is based on hydrocarbon sources [2] putting constraints on the surplus production for domestic consumption instead of exports. To further exacerbate the problems GCC countries have yet to implement smart grids and adaptive demand management solutions for effective transmission and distribution. Fossil fuel combustion is widely recognized to be the most significant contributor to the GHG emissions. The increase in electricity demand in the GCC countries far exceeds the global average, due to the growing economic base and the associated development projects in the region. Three of the GCC countries are identified by the United Nations Environmental program as having the highest per capita energy consumption worldwide. The GCC country-wise contribution to the total GHG emission in the year 2005 was: 56% by Saudi Arabia, 18.75% by the UAE, 10.43% by Kuwait, 7.3% by Qatar, 4% by Oman and 3.4% by Bahrain respectively [3]. One potential option for GCC is the inclusion of renewable sources from solar and wind to augment electricity production.

Some developments to integrate renewables in the energy mix can be seen in each GCC country. The UAE have developed 100 MW CSP (Shams) and 100 MW solar PV (Noor project), Mohammed Bin Rashed Solar Park with an anticipated capacity of 1000 MW by year 2030, and Masdar city promoting research in renewable energy technologies. Qatar plans to cool the stadiums using solar power in hosting the 2022 FIFA World Cup, and control GHG emissions. Bahrain and Oman have launched pilot projects for renewable energy generation. Kuwait is heading towards setting up a 60 MW solar power plant. Saudi Arabia's recent investments in alternative energies include solar power to run anti-corrosion control panel devices, trials to power a village and a school using solar energy, the planned polysilicon production facilities in the country (IDEA polysilicon) and 100 MW and 600 MW solar projects in Makkah and Dibba respectively [4]. These projects in the GCC nations also entail numerous indirect benefits including creating a local skilled employment, reducing the dependence on fossil fuels for power generation and localized industrial development with huge domestic demand and export potential. On the other hand these targets for improving energy efficiency and reducing GHG emissions are not trivially achievable as they come with significant challenges. These include research and development relevant to the local needs associated with carrying out such projects (for instance dust, humidity and heat are unique to the location that can render the existing technologies inefficient). The subsidized use of hydrocarbons currently supported by the GCC governments also requires proper management to channel investments in renewable energy. The cost of solar power generation is at least six times higher than power generation using the subsidized gas [4].

In this paper we present a multi-criteria model using Weighted Goal Programming (WGP) technique to study optimal resource allocation with conflicting objectives related to GDP growth, electricity consumption, GHG emissions and number of employees towards achieving sustainability goals by the year 2030 for GCC countries. The results of the model offer policy makers options to explore trade-offs between competing objectives, assess strengths and weaknesses in simultaneously achieving sustainability goals and address the shortcomings through coordinated policy planning and development. Most existent literature on economic–environmental–energy model uses time series based approach, panel co-integration, and Granger causality tests. Our approach employs a multi-criteria model for GCC countries. Although goal programming (GP) approach and its variants have been used to study and plan policies for individual countries, to the best of our knowledge this is the first approach to use multi-criteria approach applied to GCC countries that allows comparative analysis.

The rest of the paper is organized as follows: in Section 2, we present relevant literature on multi-criteria models using goal programming applied to study energy–economic–environmental interactions. In Section 3 we introduce the mathematical formulation of multi-criteria model using GP technique, in Section 4 we present the data and estimated goals used to validate the model. In Section 5, we discuss the model results and their interpretation and present conclusions in Section 6.

2. Related literature

Resource planning problems often involve economic, environmental and social objectives that are in conflict with one another. As pointed out by Dincer and Rosen [5] there is an intimate connection between energy, the environment and sustainable development. Multi-criteria decision models using goal programming techniques have been applied to a variety of energy planning, energy resource allocation, building energy management, transportation energy management, and planning for energy projects [6–12]. Indeed different stakeholders bring along different criteria and points of view, which must be resolved within a framework of understanding and mutual compromise.

The traditional energy-resources allocation problem is concerned with the allocation of limited resources among the end-uses such that the overall return is maximized. Mezher et al. [13] study the energy allocation process from two points of view: economy (costs, efficiency, energy conservation, and employment generation) and environment in Lebanon. The objective functions were transformed into mathematical language to obtain a multi-objective allocation model based on pre-emptive GP techniques. The proposed method allows decision makers to encourage or discourage specific energy resources for the various household end-uses. The review by Wang et al. [14] highlights the popularity of MCDA methods in decision-making for sustainable energy due to multi-dimensionality of the sustainability goals and the complexity of socio-economic and biophysical systems. Researchers emphasize that most countries are faced with important challenges concerning the definition of the policies to achieve energy and environmental targets, taking also into account the economic and social issues. Main recent contributions on this issue follow.

Ren et al. [15] develop a multi-objective Mixed Integer Linear Programming (MILP) model to investigate an optimal operating strategy of a distributed energy system, considering the economic and environmental aspects. San Cristóbal [16] analyzes how targets for the emissions of GHGs may be reached and can affect the composition of production activity in Spain, considering a GP model across key economic sectors, minimizing GHG emissions, waste emissions, and energy requirements, and maximizing employment and output levels. Henriques and Antunes [17] construct an Input/Output multi-objective linear programming model for the Portuguese economy to assess the trade-offs between the maximization of GDP and employment level, and the minimization of energy imports and environmental impacts, tackling the uncertainty of the model coefficients using interval programming. Carvalho et al. [18] consider simultaneously economic and environmental criteria in the synthesis of a trigeneration system to be installed in a hospital. A MILP model provides a Pareto frontier set of solutions representing optimal trade-offs between the economic and environmental objectives. Chang [19] employs a GP model to identify the key CO_2 emitting sectors for optimized production structure applied to emission reduction goals of China. Flores et al. [20] present a mathematical programming model that helps plan investment in energy sources. The model uses renewable and non-renewable demands and sources of new