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.

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...
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, the 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 Rashid 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 CO₂ 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

Please cite this article in press as: Jayaraman R et al. A Weighted Goal Programming model for planning sustainable development applied to Gulf Cooperation Council Countries. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2016.04.065
energy facilities and the current amount of fossil-fuel reserves in order to maximize the Net Present Value in time.

An emerging literature stream is focusing on the Middle East and North Africa (MENA) and/or the GCC countries. Ozturk and Acaravci [21] investigate the short and long run causality issues between electricity consumption and economic growth in MENA countries by using Autoregressive Distributed Lag (ARDL) bounds testing approach of cointegration and vector error-correction models. The overall results indicate that there is no relationship between the electricity consumption and the economic growth in most of the MENA countries. Ozturk and Al-Mulali [22] investigate the relationship between natural gas energy consumption and economic growth by including trade openness, total labor force and gross fixed capital formation as major determinants of GDP growth within a multi-variate framework model for GCC countries. Asif et al. [23] capture the relationships amongst energy consumption, urbanization, economic growth and environmental degradation in the GCC countries by using panel unit root and co-integration tests for the period 1980–2011. A MILP formulation is presented for the optimal design of UAE power system by Almansoori and Betancourt-Torcat [24]. They study the 2020 UAE power sector operations under three scenarios: domestic vs. international natural gas prices (considering different carbon tax levels), social benefits of using low emission power technologies (e.g., renewable and nuclear), and CO₂ emission constraints. Recently, Jayaraman et al. [25] develop a polynomial GP model to study the effects of electricity consumption and GHG emissions on the economic growth of United Arab Emirates (UAE).

Jayaraman et al. [26] propose a fuzzy GP model that integrates optimal resource allocation to simultaneously satisfy prospective goals on economic development, energy consumption, workforce, and greenhouse gas emission reduction applied to key economic sectors of the UAE. Jayaraman et al. [27,28] study optimal labor allocation for energy, economic and environmental sustainability of the UAE using a WGP approach.

The current paper falls within this literature stream, as we extend the work presented in Jayaraman et al. [27] to compare policies across the GCC countries. This paper does not consider the perspective of a single country, as geographic and environmental reasons suggest that it is better to take into account the GCC area as a whole. Our model fits into multi-criteria models in line with the presented literature review: as we will show in the next section, our model includes four criteria namely gross domestic product, electricity consumption, GHG emissions, and the number of employees across major economic sectors. We present a WGP model to simultaneously satisfy prospective goals on economic development, energy consumption, workforce, and greenhouse gas emission reduction applied to key economic sectors of the UAE. Jayaraman et al. [27,28] study optimal labor allocation for energy, economic and environmental sustainability of the UAE using a WGP approach.

3. Model formulation using MCDM and goal programming

Multi-criteria decision making (MCDM) refers to making decisions in the presence of multiple, usually conflicting and incommensurable criteria. MCDM problems are common in everyday life and very often real world problems are modeled using this framework. MCDM techniques provide solutions that can be considered the best compromise satisfying multiple criteria involved in the model. MCDM problems are more complicated than single criterion optimization and usually of large scale. Although MCDM problems are very well known since the 1950s MCDM as a discipline only has a relatively short history and its development is closely related to the advancement of algorithms and computing systems.

The GP techniques have become a widely used approach in Operations Research (OR); the classical GP model and its variants have been applied to solve large-scale MCDM problems. Within the GP philosophy each criteria is provided with a goal or target value to be achieved, and unwanted deviations from this set of target values are then minimized by the objective function. The obtained solution through the GP model represents the best compromise that can be made by the decision maker. A positive feature of the GP philosophy is its simplicity and ease of use [29], which justify its wide popularity for solving MCDM models in diverse fields. GP model has been widely applied in several disciplines including: accounting and financial aspect of stock management, marketing, quality control, human resources, production and operations management [30–33]. A negative counterpart is the ability of the GP model to produce solutions that are not Pareto efficient, but there are methods to improve Pareto efficiency in solutions. The GP model was first introduced by Charnes and Cooper [34,35], and in the classical formulation it takes the following form:

Minimize \( \sum_{i=1}^{p} D_{i}^{+} + D_{i}^{-} \)

Subject to

\( \sum_{j=1}^{n} A_{ij} X_{j} + D_{i}^{-} - D_{i}^{+} = G_{i}, \quad i = 1 \ldots p \)

\( X \in \Omega \)

\( D_{i}^{-}, D_{i}^{+} \geq 0, \quad i = 1 \ldots p \)

where \( \Omega \) is the feasible set, \( X_{j} \) are the input variables representing the number of employees in each economic sector, the coefficient \( A_{ij} \) states the contribution of the \( j \)th variable to the achievement of the \( i \)th criterion \( F_{i}(X_{1}, X_{2}, \ldots, X_{n}) = \sum_{j=1}^{n} A_{ij} X_{j} \). \( D_{i}^{-} \) and \( D_{i}^{+} \) are, respectively, the positive and the negative deviations with respect to the aspiration goal levels \( G_{i} \). The interpretation of model (1) is quite straightforward: the smaller the deviations from the desired goals the better the solution \( X = (X_{1}, \ldots, X_{n}) \) is, meaning that the achieved levels \( \sum_{j=1}^{n} A_{ij} X_{j} \) for each criterion are getting closer to the set goals \( G_{i} \). Jones and Tamiz [36] discuss various GP variants and solution methodology. An alternative definition of GP Model is the Weighted GP represented as:

Minimize \( \sum_{i=1}^{p} W_{i}^{+} D_{i}^{+} + W_{i}^{-} D_{i}^{-} \)

Subject to

\( \sum_{j=1}^{n} A_{ij} X_{j} + D_{i}^{-} - D_{i}^{+} = G_{i}, \quad i = 1 \ldots p \)

\( X \in \Omega \)

\( D_{i}^{-}, D_{i}^{+} \geq 0, \quad i = 1 \ldots p \)

where \( W_{i}^{+} \) and \( W_{i}^{-} \) represent weights associated with positive and negative deviations of each goal.

In this paper we formulate a macroeconomic WGP growth model that simultaneously considers the following four sustainability criteria:

- \( F_{1} = \text{gross domestic product (in local currency)} \)
- \( F_{2} = \text{Electricity consumption (in Gwh)} \)
- \( F_{3} = \text{GHG emissions (in Gg of CO₂ equivalent)} \)
- \( F_{4} = \text{Number of employees (in thousands)} \)
where criterion \( F_i \) is linear with respect to the decision variable \( X_j \) and takes the form

\[
F_1(X_1, X_2, \ldots, X_8) = A_{11}X_1 + A_{12}X_2 + \ldots + A_{18}X_8 \\
F_2(X_1, X_2, \ldots, X_8) = A_{21}X_1 + A_{22}X_2 + \ldots + A_{28}X_8 \\
F_3(X_1, X_2, \ldots, X_8) = A_{31}X_1 + A_{32}X_2 + \ldots + A_{38}X_8 \\
F_4(X_1, X_2, \ldots, X_8) = A_{41}X_1 + A_{42}X_2 + \ldots + A_{48}X_8 
\]

The decision variable in our proposed model \( X_j \) represents the number of employees in each economic sector, we consider the following eight economic sectors:

- \( X_1 = \) Agriculture
- \( X_2 = \) Crude oil, Natural Gas & Mining
- \( X_3 = \) Manufacturing & Electricity
- \( X_4 = \) Construction & Real Estate
- \( X_5 = \) Trade & Transport
- \( X_6 = \) Restaurants & Hotels
- \( X_7 = \) Banking & Financial Services
- \( X_8 = \) Government, Social & Personal Services

For each criterion, four goals \( C_1, C_2, C_3, \) and \( C_4 \) are obtained by projecting the past trends. Finally each decision variable is bounded from below by a non-zero positive number \( \Omega_i \), meaning that each decision has to preserve at least the current number of employees in each sector. Summarizing, the following WGP model with weights \( W_1, W_2, W_3, W_4 \), is implemented as

\[
\text{Minimize } \quad W_1(D_{11} + D_{12}) + W_2(D_{21} + D_{22}) + W_3(D_{31} + D_{32}) + W_4(D_{41} + D_{42}) \\
\text{Subject to } \quad \begin{align*}
A_{11}X_1 + A_{12}X_2 + \ldots + A_{18}X_8 + D_{11} - D_{12} &= C_1 \\
A_{21}X_1 + A_{22}X_2 + \ldots + A_{28}X_8 + D_{21} - D_{22} &= C_2 \\
A_{31}X_1 + A_{32}X_2 + \ldots + A_{38}X_8 + D_{31} - D_{32} &= C_3 \\
A_{41}X_1 + A_{42}X_2 + \ldots + A_{48}X_8 + D_{41} - D_{42} &= C_4 \\
X_1 &\geq \Omega_1; \quad X_2 &\geq \Omega_2; \quad X_3 &\geq \Omega_3; \quad X_4 &\geq \Omega_4; \quad X_5 &\geq \Omega_5; \\
X_6 &\geq \Omega_6; \quad X_7 &\geq \Omega_7; \quad X_8 &\geq \Omega_8; \\
X_{j, i} &\in \{1, 2, 3, \ldots, 8\} \text{ are integer} \\
D_{1i}, D_{2i}, D_{3i}, D_{4i}, D_{42} &\geq 0
\end{align*}
\]

The variables \( D_{11}, D_{12}, D_{21}, D_{22}, D_{31}, D_{32}, D_{41}, D_{42} \) represent the positive and negative deviations with the conventional notation \( D_{1i} = D_i^+ \) and \( D_{2i} = D_i^- \). The input variables \( X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8 \) take integer values, thus the proposed WGP model takes the form of the Mixed Integer Linear Programming model. For each country we implement the model (3). The mathematical representation for each country is presented in Appendix A. The sectoral data and the goals for various criteria are discussed in Section 4.

4. Model data and analysis

In validating the WGP model (3) for the six GCC countries, we consider the contribution of eight key economic sectors for the identified four criterion: gross domestic product (\( F_1 \)), electricity consumption (\( F_2 \)), GHG emissions (\( F_3 \)), and total number of employees (\( F_4 \)). Sectoral estimates were collected from several sources, in cases where the available data was missing or limited, reasonable values were estimated based on past trends. In this section we present the data discuss the assumptions and used in estimation of goals for numerical validation.

Fig. 1 presents the historical trends of the four model criteria between the years 2000–2012. For comparison the GDP data for each country is in US dollars. It is characteristic that GDP growth has been rapidly rising with a slight deflection in the year 2008. Total population and electricity consumption preserve a steadily increasing trend. For GHG emission, the trend of CO\(_2\) emissions is presented as it represents a major contributor to GHG emissions. Data for the trends on GDP, population growth and CO\(_2\) emissions were obtained from World Bank data bank and electricity consumption were obtained from U.S. Energy Information Administration.

4.1. Gross domestic product

Sector wise GDP are published in annual statement of national accounts by Ministry of Economy, Central Bank of respective countries. In some cases the most updated entry was unavailable, and we used the estimated annual percentage growth rate of GDP based on constant growth in local currency from World Bank data bank. Table 1 presents the sector wise per capita estimates of GDP with reference to the year 2014.

4.2. Electricity consumption

The per capita estimates for electricity consumption across the eight sectors in Gigawatt hour (Gwh) are summarized in Table 2. The sectoral data for electricity consumption was obtained from the International Energy Agency (IEA) with reference to the year 2011.3 The data from IEA did not provide sector specific estimates on electricity consumption; hence we estimate the percentile contribution of each sector relative to GDP and used it as measure of disaggregation to estimate sector specific values for electricity consumption with reference to year 2014.

4.3. GHG emissions

GHG emission data was obtained from the United Nations Framework Convention on Climate Change (UNFCCC). Table 3 summarizes the sector specific per capita GHG emissions in Giga Grams of CO\(_2\) equivalent. All the six GCC countries are identified as non-annex I parties with no reporting burden. The most updated entry available for each country is as follows: Qatar (2007), UAE (2005), KSA (2000), Bahrain (2000), Oman (1994) and Kuwait (1994). The past trend of sector wise GHG were used to project the data with reference to the year 2012.

4.4. Number of employees

The number of employees across the eight economic sectors were obtained from Ministry of Labor, Statistics Planning and Development of respective countries. Table 4 presents the number of employees (in thousands) employed in each sector. The annual growth percentage of labor was used to project the data with reference to year 2014.
Fig. 1. Historic trends in GDP, electricity consumption, GHG emissions and population growth. * Data sources: World Development Indicators Database, World Bank; U.S. Energy Information Administration.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Gross domestic product per capita.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Sector</td>
</tr>
<tr>
<td>X1</td>
<td>Agriculture</td>
</tr>
<tr>
<td>X2</td>
<td>Crude oil, Natural Gas &amp; Mining</td>
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<tr>
<td>X3</td>
<td>Manufacturing &amp; Electricity</td>
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<tr>
<td>X4</td>
<td>Construction &amp; Real Estate</td>
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<tr>
<td>X5</td>
<td>Trade &amp; Transport</td>
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<td>X6</td>
<td>Restaurants &amp; Hotels</td>
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<tr>
<td>X7</td>
<td>Banking &amp; Financial Services</td>
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<tr>
<td>X8</td>
<td>Government, Social &amp; Personal Services</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Electricity consumption per capita (in Gwh, reference year 2014).</th>
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<tr>
<td>Variable</td>
<td>Sector</td>
</tr>
<tr>
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Estimated goals by the year 2030 for various model criteria.

Table 5 presents the projected goal values for the year 2030 with the corresponding growth rates for the four criteria. The growth in population and rising labor force participation in GCC is estimated to be between 3% and 4% and we set the average growth rate of 3.5%. The GDP growth rates were estimated based on past trends of data reported to UNFCCC. Electricity consumption growth rates were estimated from IEA data and similarly GHG emissions were estimated from World Bank. Electricity consumption growth rates were estimated based on data from World Bank. Electricity consumption growth rates were estimated based on past trends of data reported to UNFCCC.

### 5. Results and interpretation

The WGP model was solved using optimization software LINGO 14. The respective mathematical optimization model for each country is presented in the Appendix A.

The results in Table 6 can be interpreted as follows:

Regarding GDP growth, Qatar is the only country that shows a consistent negative deviation ($D_{21} = 423637.6$) with respect to its current trend, implying that the long-run macroeconomic scenario will not permit a GDP growth in line with the current trends. A positive deviation of $D_{22}$ for the case of Bahrain, Saudi Arabia, Oman, and Qatar indicates that GHG emissions in these countries are expected to grow beyond the current trends.

Regarding the energy consumption criterion, only the UAE shows a consistent nonzero positive deviation ($D_{22} = 30606.7$) which suggests that investments in green and renewable energy resources have to be implemented to satisfy the current demand of energy consumption without any further increase in the total GHG emissions. This observation is consistent with findings in [28]. In addition the surplus in $D_{21}$ for Bahrain, Oman and Qatar indicates that the long run energy requirements will be met. Interpreted together with $D_{22}$ suggests a strong need to diversify energy production using renewables.

The model provides policy makers a quantitative tool to simultaneously optimize and assess trade-offs between multiple sustainability criteria. Previous research has widely recognized the strong interdependencies between energy consumption, GDP growth and GHG emissions. The results of the WGP model indicate GDP growth (except Qatar) and number of employees goals are attainable but a combination of policy tools should encourages future investments in clean technologies, novel ways for energy storage [37], innovative ways to capture, store and transport CO₂ emissions [38,39], promoting judicious use of energy resources goes hand-in-hand to enhance the future energy security, and permit healthy economic and environmental growth in GCC countries.

### 6. Conclusions

Rapid economic development and industrialization go hand in hand with increased energy use, GHG emissions and labor demand require careful planning and exploring potential tradeoffs among competing objectives. The last few decades have witnessed a growing concern on resource consumption, the adequacy of energy resources and with the quality of the physical environment. Recently, the GCC countries have shown a keen interest in...
engaging in a more sustainable development path, with many of them are already pursuing strategic energy options beyond hydrocarbons by integrating nuclear power generation and renewable sources in their energy portfolio [40,41].

The WGP model results show that GHG emissions goal is not achievable by four out of six GCC countries thus there is a significant need to refocus their investments on energy efficiency, conservation and incrementing the share of renewable, non-emitting sources of energy production in order to achieve sustainable development in the long term. Furthermore the model provides insights that all other goals may be achieved with two exceptions (GDP for Qatar and electricity consumption for the UAE). It is well known that investments in pollution abatement activities impact on GDP: A portion of GDP has to be used to financing technology progress, innovation, and acquisition of skilled labor. Obviously, this scenario might have a negative impact on the achievement of all other goals and on the overall long-run sustainability.

Acknowledgements

The authors gratefully acknowledge the support and funding from Khalifa University Internal Research Fund (KUIRF) – Grant number 210032 to conduct this research. Cinzia Colapinto gratefully acknowledges financial support from Ca’ Foscari University of Venice.

Appendix A

A.1. Bahrain

\[
\begin{align*}
\text{MINIMIZE} & \ 0.25(D_{11} + D_{12}) + 0.25(D_{21} + D_{22}) + 0.25(D_{31} + D_{32}) \\
& + 0.25(D_{41} + D_{42});
\end{align*}
\]

A.1.1. GDP constraint

\[
\begin{align*}
0.06285X_1 + 0.23323X_2 + 0.05118X_3 + 0.01739X_4 + 0.02089X_5 \\
+ 0.04577X_6 + 0.30844X_7 + 0.02656X_8 + D_{11} - D_{12} = 643477;
\end{align*}
\]

A.1.2. Electricity consumption constraint

\[
0.03688X_1 + 0.00505X_2 + 0.05018X_3 + 0.03949X_4 + 0.02047X_5 \\
+ 0.04438X_6 + 0.30233X_7 + 0.02721X_8 + D_{21} - D_{22} = 905527;
\]

A.1.3. GHG emission constraint

\[
0.02138X_1 + 0.42291X_2 + 0.09047X_3 + 0.02858X_4 + 0.01375X_5 \\
+ 0.02213X_6 + 0.15673X_7 + 0.01349X_8 + D_{31} - D_{32} = 592376;
\]

A.1.4. Number of employees constraint

\[
\begin{align*}
X_1 & + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + D_{41} - D_{42} = 1337222; \\
X_1 & \geq 1418; \quad X_2 \geq 26948; \quad X_3 \geq 89156; \quad X_4 \geq 185668; \quad X_5 \geq 163034; \quad X_6 \geq 36995; \quad X_7 \geq 16371; \quad X_8 \geq 194364; \\
D_{11} & \geq 0; \quad D_{12} \geq 0; \quad D_{21} \geq 0; \quad D_{22} \geq 0; \quad D_{31} \geq 0; \quad D_{32} \geq 0; \quad D_{41} \geq 0; \quad D_{42} \geq 0;
\end{align*}
\]

A.2. Kuwait

\[
\begin{align*}
\text{MINIMIZE} & \ 0.25(D_{11} + D_{12}) + 0.25(D_{21} + D_{22}) + 0.25(D_{31} + D_{32}) \\
& + 0.25(D_{41} + D_{42});
\end{align*}
\]

A.2.1. GDP constraint

\[
\begin{align*}
0.0029949X_1 + 6.786261X_2 + 0.0305775X_3 + 0.0719705X_4 \\
+ 0.0254195X_5 + 0.0192644X_6 + 0.5393307X_7 + 0.0763199X_8 \\
+ D_{11} - D_{12} = 299999;
\end{align*}
\]

A.2.2. Electricity consumption constraint

\[
\begin{align*}
0.00154206X_1 + 1.427194698X_2 + 0.001573683X_3 \\
+ 0.03701313X_4 + 0.0130792X_5 + 0.00991595X_6 \\
+ 0.277654967X_7 + 0.039264768X_8 + D_{21} - D_{22} = 135470;
\end{align*}
\]
A.2.3. GHG emission constraint

\[
0.00537608X_1 + 13.66335466X_2 + 0.007849185X_3 \\
+ 0.018493317X_4 + 0.057050391X_4 + 0.004950058X_6 \\
+ 0.138600805X_7 + 0.019615459X_8 + D_{31} - D_{32} = 1264670;
\]

A.2.4. Number of employees

\[
X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + D_{41} - D_{42} = 2966679; \\
X_1 \geq 75250; \quad X_2 \geq 10940; \quad X_3 \geq 163273; \quad X_4 \geq 237774; \\
X_5 \geq 608856; \quad X_6 \geq 173002; \quad X_7 \geq 43961; \quad X_8 \geq 278878; \\
D_{11} \geq 0; \quad D_{12} \geq 0; \quad D_{21} \geq 0; \quad D_{22} \geq 0; \quad D_{31} \geq 0; \quad D_{32} \geq 0; \\
D_{41} \geq 0; \quad D_{42} \geq 0;
\]

A.3. WGP model for OMAN

\[
\text{MINIMIZE} \ 0.25(D_{11} + D_{12}) + 0.25(D_{21} + D_{22}) + 0.25(D_{31} + D_{32}) \\
+ 0.25(D_{41} + D_{42});
\]

A.3.1. GDP constraint

\[
0.0046995X_1 + 1.0059403X_2 + 0.0216246X_3 + 0.0047058X_4 \\
+ 0.0190412X_5 + 0.0031376X_6 + 0.3923977X_7 + 0.0282132X_8 \\
+ D_{11} - D_{12} = 190890;
\]

A.3.2. Electricity consumption constraint

\[
0.00375X_1 + 0.0477X_2 + 0.00961X_3 + 0.01725X_4 + 0.00846X_5 \\
+ 0.00139X_6 + 0.17409X_7 + 0.04499X_8 + D_{21} - D_{22} = 80767;
\]

A.3.3. GHG emission constraint

\[
0.135224938X_1 + 0.761112323X_2 + 0.008569463X_3 \\
+ 0.001858961X_4 + 0.012846627X_5 + 0.001235809X_6 \\
+ 0.15465536X_7 + 0.011141805X_8 + D_{31} - D_{32} = 571667;
\]

A.3.4. Number of employees constraint

\[
X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + D_{41} - D_{42} = 2620394; \\
X_1 \geq 82067; \quad X_2 \geq 15824; \quad X_3 \geq 167444; \quad X_4 \geq 673878; \\
X_5 \geq 191608; \quad X_6 \geq 78878; \quad X_7 \geq 3663; \quad X_8 \geq 185688; \\
D_{11} \geq 0; \quad D_{12} \geq 0; \quad D_{21} \geq 0; \quad D_{22} \geq 0; \quad D_{31} \geq 0; \quad D_{32} \geq 0; \\
D_{41} \geq 0; \quad D_{42} \geq 0;
\]

A.4. WGP model for Qatar

\[
\text{MINIMIZE} \ 0.25(D_{11} + D_{12}) + 0.25(D_{21} + D_{22}) + 0.25(D_{31} + D_{32}) \\
+ 0.25(D_{41} + D_{42});
\]

A.4.1. GDP constraint

\[
0.0071491X_1 + 0.4085752X_2 + 0.0834765X_3 + 0.0344194X_4 \\
+ 0.0485242X_5 + 0.1313356X_6 + 0.522864X_7 + 0.034663X_8 \\
+ D_{11} - D_{12} = 859855;
\]

A.4.2. Electricity consumption constraint

\[
0.00278X_1 + 0.03333X_2 + 0.10085X_3 + 0.02057X_4 + 0.01749X_5 \\
+ 0.04555X_6 + 0.22672X_7 + 0.0133X_8 + D_{21} - D_{22} = 190478;
\]

A.4.3. GHG emission constraint

\[
0.00614X_1 + 0.63139X_2 + 0.06614X_3 + 0.00401X_4 + 0.03152X_5 \\
+ 0.0552X_6 + 0.27507X_7 + 0.01646X_8 + D_{31} - D_{32} = 274311;
\]

A.4.4. Number of employees constraint

\[
X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + D_{41} - D_{42} = 2687870; \\
X_1 \geq 19433; \quad X_2 \geq 88929; \quad X_3 \geq 118204; \quad X_4 \geq 545587; \\
X_5 \geq 234428; \quad X_6 \geq 34459; \quad X_7 \geq 12260; \quad X_8 \geq 381776; \\
D_{11} \geq 0; \quad D_{12} \geq 0; \quad D_{21} \geq 0; \quad D_{22} \geq 0; \quad D_{31} \geq 0; \quad D_{32} \geq 0; \\
D_{41} \geq 0; \quad D_{42} \geq 0;
\]

A.5. WGP model for Saudi Arabia

\[
\text{MINIMIZE} \ 0.25(D_{11} + D_{12}) + 0.25(D_{21} + D_{22}) + 0.25(D_{31} + D_{32}) \\
+ 0.25(D_{41} + D_{42});
\]

A.5.1. GDP constraint

\[
0.1160845X_1 + 9.3745368X_2 + 0.43333X_3 + 0.17720X_4 \\
+ 0.1320627X_5 + 0.4997924X_6 + 1.1896018X_7 + 0.0844018X_8 \\
+ D_{11} - D_{12} = 1925490;
\]

A.5.2. Electricity consumption constraint

\[
0.0098X_1 + 0.15103X_2 + 0.01701X_3 + 0.07328X_4 + 0.00518X_5 \\
+ 0.01959X_6 + 0.0467X_7 + 0.01553X_8 + D_{21} - D_{22} = 584589;
\]

A.5.3. GHG emission constraint

\[
0.04756X_1 + 1.7271X_2 + 0.04893X_3 + 0.01153X_4 + 0.04931X_5 \\
+ 0.09263X_6 + 0.22052X_7 + 0.01567X_8 + D_{31} - D_{32} = 1346292;
\]

A.5.4. Number of employees constraint

\[
X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + D_{41} - D_{42} = 20416224; \\
X_1 \geq 461948; \quad X_2 \geq 120896; \quad X_3 \geq 776809; \quad X_4 \geq 1808873; \\
X_5 \geq 2096694; \quad X_6 \geq 264920; \quad X_7 \geq 122752; \quad X_8 \geq 5247497;
\]
A.6. WGP model for United Arab Emirates

**MINIMIZE** 0.25(D₁ + D₁₂) + 0.25(D₂₁ + D₂₂) + 0.25(D₁₃ + D₁₂) + 0.25(D₁₄ + D₁₂);

A.6.1. GDP constraint

0.035705X₁ + 4.762018X₂ + 0.183853X₃ + 0.085018X₄ + 0.179355X₅ + 0.082073X₆ + 1.06595X₇ + 0.09702X₈ + D₁₁

– D₁₂ = 3110323;

A.6.2. Electricity consumption constraint

0.005358X₁ + 0.066171X₂ + 0.028007X₃ + 0.020969X₄ + 0.018068X₅ + 0.008266X₆ + 0.162398X₇ + 0.009761X₈ + D₂₁

– D₂₂ = 361513;

A.6.3. GHG emission constraint

0.018356X₁ + 1.823233X₂ + 0.07039X₃ + 0.002837X₄ + 0.006638X₅ + 0.002741X₆ + 0.035564X₇ + 0.003239X₈ + D₃₁

– D₃₂ = 286051;

A.6.4. Number of employees

X₁ + X₂ + X₃ + X₄ + X₅ + X₆ + X₇ + X₈ + D₄₁ − D₄₂ = 9115735;

X₁ ≥ 258867;  X₂ ≥ 74284;  X₃ ≥ 687686;  X₄ ≥ 1505931;

X₅ ≥ 1403509;  X₆ ≥ 236357;  X₇ ≥ 81037;  X₈ ≥ 810366;

D₁₁ ≥ 0;  D₁₂ ≥ 0;  D₂₁ ≥ 0;  D₂₂ ≥ 0;  D₃₁ ≥ 0;  D₃₂ ≥ 0;

D₄₁ ≥ 0;  D₄₂ ≥ 0;

References


