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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.

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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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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.

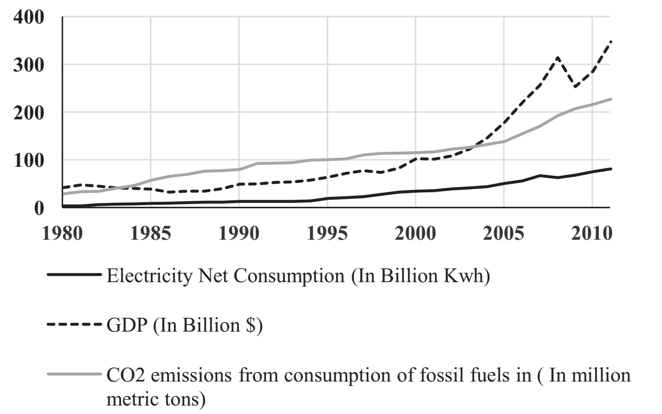

Fig. 1. Net electricity consumption, GDP growth and CO_2 emissions from fossil fuels in the UAE (Data Source: US Energy Information Association & World Bank).

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

$$\begin{aligned} & Min f(x) \\ & \text{Subject to} \\ & x \in D \end{aligned} \quad (1)$$

We say that a point $\hat{x} \in D$ is a global Pareto optimal solution or global Pareto efficient solution if $f(x) \in f(\hat{x}) + (-R_+^p \backslash \{0\})^c$ for all $x \in D$ Practically speaking, a Pareto optimal solution describes a state in which goods and resources are distributed in such a way that it is not possible to improve a single criterion without also causing at least one other criterion to become worse off than before the change. On the contrary, if a point $x \in D$ is not Pareto efficient, there is potential for a Pareto improvement and an increase in Pareto efficiency.

If $[f_1(x), f_2(x), \ldots, f_p(x)]$ is the vector of criteria to be optimized, $[g_1, g_2, \ldots, g_p]$ is the vector of the goal values of the criteria and D is the feasible set, the standard mathematical formulation of the GP model (Charnes, et al., 1955) is given by:

$$\begin{aligned} & \text{Min } Z = \sum_{i=1}^{p} \delta_i^+ + \delta_i^- \\ & \text{Subject to} \\ & f_i(x) + \delta_i^- - \delta_i^+ = g_i, \; i = 1 \ldots p \\ & x \in D; \end{aligned} \quad (2)$$

where δ_i^+, δ_i^- are, respectively, the negative and the positive deviations with respect to the aspiration levels $g_i, i = 1 \ldots p$. An alternative formulation of the GP model, which is employed in this paper is the Weighted Goal Programming (WGP) given below:

$$\begin{aligned} & \text{Min } Z = \sum_{i=1}^{p} w_i^+ \delta_i^+ + w_i^- \delta_i^- \\ & \text{Subject to} \\ & f_i(x) + \delta_i^- - \delta_i^+ = g_i, \; i = 1 \ldots p \\ & \delta_i^-, \delta_i^+ \geq 0, \; i = 1 \ldots p \\ & x \in D; \end{aligned} \quad (3)$$

where w_i^+, w_i^- are the weights associated with the negative and the positive deviations with respect to each goal. The decision maker can show different appreciation of the positive and negative deviations based on the relative importance of the objectives. We refer the reader to Jones and Tamiz (2010) for expanded details on various GP variants and their applications.

2.2. *Goal Programming applied to energy, economics and environment*

Multi-criteria decision models using GP have been extensively applied to study energy, economic and environmental problems to assist decision makers in developing sustainable policies. Indeed, MCDM models assume that numerous criteria are important in the policy formulation process and can be used to screen and select alternatives. Several literature reviews confirm the popularity of MCDM models (Wang et al., 2009; Greening and Bernow, 2004). Recently, Oliveira et al. (2014) survey different modeling approaches on coupling Input–Output analysis with multi-objective models that are useful for policy makers to assess the trade-offs between the economy, energy, the environment, and the social pillars of sustainable development. Huang et al. (2011) reviews trends and tools of MCDA for environmental applications over the last two decades to conclude that there is a significant growth in environmental applications due to increased decision complexity and information availability. Zhou et al. (2006) present a survey of various decision analysis studies involving energy and the environment to iterate the importance and increased attention among the research community to employ multi-criteria decision making methods. Diakoulaki et al. (2005) discuss the evolution of MCDA approaches, in the context of the emerging problems faced by energy planners and other stakeholders in energy planning and related decision situations. Pohekar and Ramachandran (2004) present a comprehensive survey on various types of multi-criteria decision models for sustainable energy planning.

GP models have been used for energy plants location (San Cristóbal, 2012b), modeling renewable energy portfolio (Daim et al., 2010).

In this paper we focus on the most commonly used variants, namely WGP and Fuzzy GP approach.

San Cristóbal (2012a) develops a GP model based on the environmental/input–output linear programming model considering economic, social, energy and environmental goals applied to Spain. In several ways our model was motivated and inspired by this work above. Our model is a WGP model that allows to compare different criteria through weights. In comparison with the model of San Cristóbal (2012a), our formulation introduces an explicit electricity consumption criterion and deals with an environmental pollution without differentiating between GHG emissions and wastes emissions. In terms of economic sectors, our model reflects the peculiarities of an oil-based Middle East economy characterized by high population and affluence.

Chang (2014) employs a GP model to identify the key CO_2 emitting sectors for optimized production structure applied to targeted emission reduction in China. André et al. (2009) consider lexicographic, weighted and max–min GP models to study the impact of alternative policy tools such as direct and indirect taxes, environmental taxes and public expenditure for macroeconomic factors such as economic growth, inflation, unemployment, public deficit and environmental goals of Spain. Oliveira and Antunes (2011) develop a multi-sectoral economy, energy, environment model for prospective analysis of the changes in the economic structure and the energy system to assess the corresponding environmental impacts in policy making for Portugal. Ballarin et al. (2011) develop a multi-period WGP model to identify optimal land use combination to maximize farm income and biomass energy production applied to Rovigo county area in Italy over a 15-year time period.

Linares and Romero (2000) develop a WGP model to study the influence of electricity production plans concerning cost and environmental (radioactive waste disposal, and emissions) criteria in Spain. Linares and Romero (2002) further extend their analysis to propose a WGP model to aggregate preferences over four different social groups with conflicting interests that includes regulators, academics, electric utilities and environmentalists. Bell et al. (2001) develop a WGP model to study and assess the impact of several climate policy alternatives based on cost and broad range of environmental indicators such as increase in global temperature, sea level rise, and stress to ecosystem. GP models concerning economic and environmental interactions have been extensively applied in planning and implementation of amenable policies. Borges and Antunes (2003) use fuzzy multiple objective decision support model to study the relationships between the economy and the energy sector on a national level applied to Portugal.

Recently, Jayaraman et al. (2015b) proposed a fuzzy GP model that integrates optimal resource allocation to simultaneously satisfy prospective goals on economic development, energy consumption, workforce, and GHG emission reduction applied to key economic sectors of the United Arab Emirates.

Our contribution in this paper adds to the growing literature on integrating optimal resource allocation to simultaneously satisfy energy, environmental and economic goals. Our WGP model can be easily extended to include additional criteria on renewable energy resources, pollution abatement efforts, and additional economic sectors.

2.3. Data preparation and analysis

In this section we discuss numerical data and assumptions of the four criteria used in the WGP model relating to GDP growth (G_1), electricity consumption (G_2), GHG emissions (G_3) and total labor (G_4) across key economic sectors of United Arab Emirates. The Social Input–Output table represents flow of economic activity, consumption patterns, investments, intermediate inputs and other related activities. Constructing a sectorial Input–Output table provides a static view of the economy and is used as a fundamental tool for policy planning and macroeconomic analysis. Data from sectorial Input–Output table provides crucial inputs to the proposed WGP model. Vellinga (2006) provide an approach to construct sectorial Input–Output table for the UAE using data from the Ministry of Economy and Planning (MOEP) and the Central Bank of the UAE. It aggregates 15 key economic sectors identified in MOEP into 8 sectors by logically grouping commodities and industries of similar types and technologies. As defined in Vellinga (2006) we use the following 8 sectors in our WGP model: (i) Agriculture (X_1), (ii) Crude oil, natural gas and quarrying (X_2), (iii) Manufacturing and electricity (X_3), (iv) Construction and real estate (X_4), (v) Trade and transport (X_5), (vi) Restaurant and hotel (X_6), (vii) Banking and financial corporations (X_7) and (viii) Government, social and personal services (X_8). Where X_i represents the number of employees in sector i. Fig. 2 presents the sector-wise itemization of the GDP, electricity consumption and the number of employees. Obtaining sector specific data for the four criteria was difficult and not direct. For some model variables we aggregate and/or disaggregate the available data.

The GDP contribution for each of the eight sectors was obtained from the 2012 annual economic report published by Ministry of Economy in the UAE. The data for electricity consumption was obtained from the International Energy Agency (IEA) with reference to the year 2011. However the data did not provide sector specific estimates; we used the percentile contribution of the GDP relative to each sector for disaggregation. The IEA data on electricity consumption was available in four categories: (a) residential, (b) industrial, (c) commercial and public services, (d) other non-specified categories. We disaggregated the data to provide estimates of consumption for the eight identified sectors. The year 2005 (being most current) data on GHG emissions were obtained from the 3rd National Communication under the United Nations Framework Convention on Climate Change (UNFCC). The total GHG emissions in the UAE were 174,357 Giga grams (Gg) of CO_2 equivalent. Energy related activities contributed the largest to GHG emissions (153,833 Gg), followed by 9,426 Gg due to industrial activity, 7,122 Gg due to waste and 3,976 Gg due to agriculture. Sequestration due to land use change and forestry yielded 13,233 Gg. In our WGP model we did not factor in the positive contribution from land use and forestry. Fig. 3 highlights the sector-wise GHG emissions in the UAE for the year 2005. The population demographics in the UAE represent a diverse mix of nationalities and the UAE citizens. In 2013, the total population in the UAE was approximately 9.34 million, of which approximately 7.8 million were expatriates. To sustain the high economic growth and standard of living the UAE is reliant on the expatriate labor force. The total labor employed in each of the eight economic sectors was obtained from the 2012 annual economic report, Ministry of Economy in UAE (UAE Ministry of Economy-Annual, 2012). Fig. 2 provides the sector-wise contribution of GDP, electricity consumption and number of employees.

To compute the numerical limits (goals) for the model we analyzed the economic and developmental objectives laid out in the UAE Vision 2021 and the Abu Dhabi Economic Vision 2030. These objectives aim to make UAE's economy less reliant on hydrocarbon-based source for revenue, by creating a resilient knowledge and innovation driven economy. This is an important step towards establishing a diversified economy and a new growth model. The goal related to GDP growth (G1), projected at 7%, is expected to be 2725 billion Dirhams (1 USD=3.68 Dirhams) by the year 2030, and the electricity consumption (G_2) is projected to 286980 Gwh by 2030 at 8% growth. We consider two possible scenarios for GHG emissions (G_3): at 2% rate of increase leading to 284739 Gg of CO_2 equivalent (scenario 1), and 590434 Gg of CO_2 equivalent to 5% rate of increase (scenario 2). The two scenarios provide marginal comparison for the effects on goals permitting a slight increase of GHG emission. The projected population growth in the UAE by the year 2030 is estimated to be 12.33 million (UN World Population Prospects: The 2012 Revision). The number of employees in the year 2012 was 4,494,000 and projecting the labor market growth at 3.75%, the estimated number of employees in year 2030 will more than double the current number to reach 9,452,000. We have used conservative estimates and rational assumptions on data from disparate data sources to validate the WGP model to study the feasibility of jointly achieving the sustainability related goals on economic, environmental, energy and resource allocation.

Table 1 provides the per-capita estimates of the contribution by each sector relative to the identified objectives.

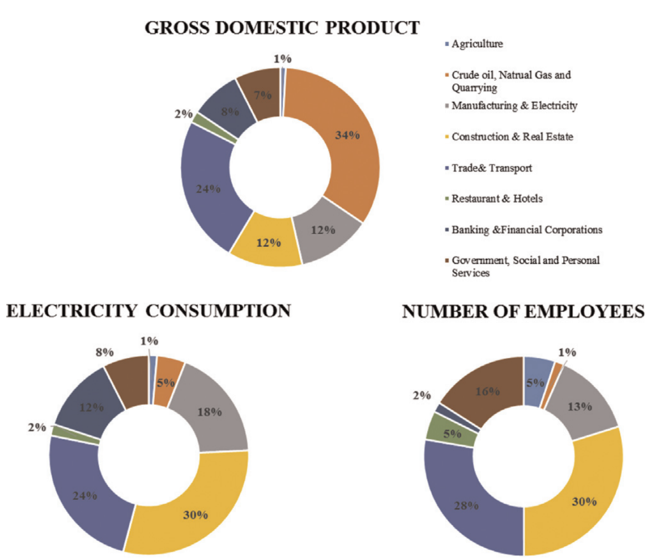

Fig. 2. Sector wise breakdown of GDP, Electricity consumption and Workforce (Data Source: UAE Ministry of Economy Annual Economic Report, UAE National Bureau of Statistics, International Energy Agency).

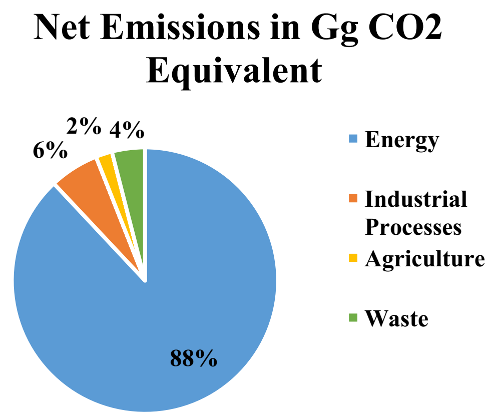

Fig. 3. Sector wise Net GHG Emissions in the UAE (Data Source: United Nations Framework Convention on Climate Change, 2013).

Table 1
Sectorial contribution of economic sectors to the identified goals.

Decision Variable	Sector	GDP per capita[*]	Electricity consumption per capita[**]	GHG emissions per capita[a]	Number of employees (in thousands, year 2010)[*]
X_1	Agriculture	0.03521739	0.00478696	0.01728696	230000
X_2	Crude Oil, Natural Gas and Quarrying	4.69696970	0.05912121	1.71707576	66000
X_3	Manufacturing & Electricity	0.18134206	0.02502291	0.06629133	611000
X_4	Construction & Real Estate	0.08385650	0.01873543	0.00267227	1338000
X_5	Trade & Transport	0.17690457	0.01614274	0.00627506	1247000
X_6	Restaurant & Hotels	0.08095238	0.00738571	0.00258095	210000
X_7	Banking & Financial Corporations	1.05138889	0.14509722	0.03349306	72000
X_8	Government, Social and Personal Services	0.09569444	0.00872083	0.00305000	720000

Data Sources:

[*] UAE Ministry of Economy Annual Economic Report, UAE National Bureau of Statistics.
[**] International Energy Agency (2011).
[a] Third Communication to United Nations Framework Convention on Climate Change.

2.4. Constraints and model formulation

The following four criteria f_1, f_2, f_3, and f_4 used in the model based on the data in Table 1. The first criterion f_1 describes the sector-wise per-capita contribution to GDP, the second criterion f_2 models the sector-wise per-capita contribution to energy consumption, the cumulative level of per capita GHG emissions across all economic sectors is measured by the third objective function f_3, and the total employed work force across all economic sectors is modeled in f_4.

$$f_1(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) = 0.03521739{*}X_1 + 4.69696970{*}X_2 + 0.18134206{*}X_3 + 0.08385650{*}X_4 + 0.17690457{*}X_5 + 0.08095238{*}X_6 + 1.05138889{*}X_7 + 0.09569444{*}X_8 \quad (4)$$

$$f_2(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) = 0.00479{*}X_1 + 0.05912{*}X_2 + 0.02502{*}X_3 + 0.1874{*}X_4 + 0.01614{*}X_5 + 0.00739{*}X_6 + 0.14510{*}X_7 + 0.00872{*}X_8 \quad (5)$$

$$f_3(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) = 0.01728696{*}X_1 + 1.71707576{*}X_2 + 0.06629133{*}X_3 + 0.00267227{*}X_4 + 0.00563352{*}X_5 + 0.00258095{*}X_6 + 0.03349306{*}X_7 + 0.00305000{*}X_8 \quad (6)$$

$$f_4(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) = X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 \quad (7)$$

Following the discussion presented in Section 2.3, we set the goals for the above criteria under two different scenarios as presented in Table 2. The input variables X_i represent the number of employees allocated in sector i, our objective is to determine the optimal allocation of employees across different sectors that can guarantee a long-run sustainability and the achievement of the desired goals. Let D_{ij} represent the deviation of i^{th} criteria (i=1,2,3,4), where j=0 represents positive deviation and j=1 denotes negative deviation with respect to the goal of each criteria.

Table 2
Values and growth rate of the identified goals.

Goals	Scenario 1 (Growth Rate)	Scenario 2 (Growth Rate)
G_1 (GDP Growth)	2725 Billion (7%)	2725 Billion (7%)
G_2 (Electricity Consumption)	286980 Gwh (8%)	286980 Gwh (8%)
G_3(GHG Emissions)	284739 Gg (2%)	590434 Gg (5%)
G_4 (Number of employees)	9452000 (3.75%)	9452000 (3.75%)

For scenario 1, the weighted GP model (3) takes the form:

$$\text{Min } Z = 0.25{*}(D_{11} + D_{12}) + 0.25{*}(D_{21} + D_{22}) + 0.25{*}(D_{31} + D_{32}) + 0.25{*}(D_{41} + D_{42})$$

Subject to

$$0.03521739{*}X_1 + 4.69696970{*}X_2 + 0.18134206{*}X_3 + 0.08385650{*}X_4 + 0.17690457{*}X_5 + 0.08095238{*}X_6 + 1.05138889{*}X_7 + 0.09569444{*}X_8 + D_{11} - D_{12} = 2725000 \quad (8)$$

$$0.00479{*}X_1 + 0.05912{*}X_2 + 0.02502{*}X_3 + 0.1874{*}X_4 + 0.01614{*}X_5 + 0.00739{*}X_6 + 0.14510{*}X_7 + 0.00872{*}X_8 + D_{21} - D_{22} = 286980 \quad (9)$$

$$0.01728696{*}X_1 + 1.71707576{*}X_2 + 0.06629133{*}X_3 + 0.00267227{*}X_4 + 0.00563352{*}X_5 + 0.00258095{*}X_6 + 0.03349306{*}X_7 + 0.00305000{*}X_8 + D_{31} - D_{32} = 284739 \quad (10)$$

Table 3
Results of Scenario 1.

Variable	Value	Reduced Cost	Variable	Value	Reduced Cost
D_{11}	0	0.25	X_1	230000	0.25568
D_{12}	5.75E-02	0	X_2	101157	1.00975
D_{21}	0	0.5	X_3	611000	0.28502
D_{22}	216906.2	0	X_4	1338000	0.31715
D_{31}	0.121338	0	X_5	5294239	0.29685
D_{32}	0	0.5	X_6	210000	0.27144
D_{41}	0	0.5	X_7	947597	0.54075
D_{42}	0	0	X_8	720007	0.27534

Table 4
Results of Scenario 2.

Variable	Value	Reduced Cost	Variable	Value	Reduced Cost
D_{11}	0	0.25	X_1	230000	0.26432
D_{12}	1.22E-02	0	X_2	295345	1.86829
D_{21}	0	0.5	X_3	611000	0.31816
D_{22}	102098	0	X_4	1338000	0.31848
D_{31}	0	0.5	X_5	4595936	0.29967
D_{32}	0.180703	0	X_6	210001	0.27273
D_{41}	0	0.5	X_7	72000	0.5575
D_{42}	0	0	X_8	2099718	0.27687

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + D_{41} - D_{42} = 9452000 \quad (11)$$

$$\begin{aligned} & X_1 \geq 230000 \\ & X_2 \geq 66000 \\ & X_3 \geq 611000 \\ & X_4 \geq 1338000 \\ & X_5 \geq 1247000 \\ & X_6 \geq 210000 \\ & X_7 \geq 72000 \\ & X_8 \geq 720000 \\ & X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8 \text{ integer} \\ & D_{ij} \geq 0 \end{aligned} \quad (12\text{-}19)$$

where the objective function takes into account the weighted summations of all positive and negative deviations of each criterion with respect to its corresponding goal. The constraints (8) to (11) above show a linear relationship among the achievement level of each criterion, the corresponding goals and the deviations. The smaller the deviations, the smaller are the differences between the achievement levels and the projected goals. The remaining constraints, (12–19), impose that the optimal solution has to preserve at least the current number of jobs. The results of scenario 1 are presented in Table 3. In a similar manner, we can formulate WGP model for scenario 2 and present the output in Table 4.

3. Results and discussion

The optimal solution of scenario 1 with 2% annual growth rate in GHG emissions is presented in Table 3, we observe the presence of a significant nonzero deviation of electricity consumption, denoted in the model by D_{22}. This result indicates that in order to jointly satisfy the four criteria will require a huge amount of electricity demand in the long run, in this case by year 2030. It is vital to realize that non-renewable, hydrocarbon-based sources alone cannot satisfy the long-term electricity demand as increased use of hydrocarbon sources in turn contributes to an increment of GHG emissions and, in consequence of this, an increment of the deviations of other criteria involved in the model.

The optimal solution of scenario 2 with 5% annual growth rate in GHG emissions is presented in Table 4. Scenario 2 explores the trade-off possibility in permitting a higher level of GHG emissions. Intuitively, in this case the value of D_{22} is less than the value obtained in scenario 1. This result can be interpreted as: by permitting a higher level of GHG emissions by increasing the GHG emission goal, one may obtain a reduction of the amount of electricity demand but not full satisfy the all the criteria by year 2030. In addition permitting higher level of GHG emissions in turn will require significant investments for pollution abatement efforts in enforcing regulations, monitoring, and employing newer sequestration approaches in the long run. With the objective to achieve the projected goals by the year 2030 and avoid any increment in the projected GHG emissions, the only reasonable alternative is to compensate the electricity demand by supplementing production via non-emitting, renewable sources.

Based on results from both the scenarios the goals related to projected economic growth, electricity consumption and targeted GHG emission while preserving the total number of jobs by the year 2030 may not be possible without additional efforts to diversify sources of electricity generation and investments in high productivity sectors. This is consistent with the UAE's current focus on high tech manufacturing, trade and service oriented economy. In addition, UAE is taking unprecedented steps to minimize the environmental impact with targeted inclusion of 7% renewable energy sources by year 2020 in the emirate of Abu Dhabi and 5% renewable energy by the year 2030 in the emirate of Dubai to supplement the growing electricity demand. Renewable energy sources are a natural extension to UAE's energy expertize and leadership role in promoting environmental sustainability. The WGP model provides a mathematical justification and reasoning for future investments and strategic planning to achieve sustainable development goals by the year 2030. The significant result from this work implies that there is a clear indication that the future electricity demand will be largely unsatisfied to help support the growth in labor in each sector, simultaneously retaining the high economic development, and minimizing the rate of GHG emissions.

4. Conclusions and policy implications

Over the recent decades economic, social, ethical and environmental co-dynamics have presented significant challenges in policy planning and implementation. Thus a multi-criteria approach is advocated to analyze and implement suitable policies for achieving long-term sustainability. In the current pluralistic society, where there is a wide decentralization and diversity of power concentration, the government should balance a multiplicity of stakeholders' interests that can affect the outcomes of policy choices. In particular, policies promoting renewable and low-carbon sources require a combination of strategies well supported by education, stakeholder involvement and financial incentives to bring down the initial costs of investment. Multi-criteria decision analysis using GP technique helps economic analysts and policy planners to consider the best compromise among several conflicting criteria. The model presented in this paper explores the optimal resource allocation to achieve sustainability related goals on GDP growth, electricity consumption, and GHG emission. An increment of GDP is always associated with increased energy consumption, contributing to increased GHG emissions.

In the UAE the success of environmental and energy policies relies on the collaboration of several actors. As pointed out by Mezher et al. (2011) the scientific and research community, business and industry, and institutions and governments are important players for the sustainable development of a country. This approach recalls the well-known Triple Helix model (Etzkowitz and Leydesdorff, 2000) to describe the current development as an interdependent relationship between science, industrial innovation and government policy. These trilateral interactions are clearly evident based on policies for the promotion of renewable energies, technology cluster in Abu Dhabi such as the Masdar initiative.

The UAE is pursuing a long-term economic diversification strategy to move away from a rentier state approach (Reiche, 2010a). The renewable energy sector can be ideally viewed as a vital engine for long-term economic growth, as it will imply job growth, economic development and a sustainable setting in a post-oil era. Due to the finiteness of fossil fuels it is crucial to adopt a pro-active approach towards environmental issues. As argued by Reiche (2010a) the re-orientation of the UAE has to pursue ecological modernization in terms of promotion of energy efficiency and renewable energy sources. The policy to invest in sustainability boosts the UAE's reputation in global arena, and could be seen as a soft power tool. Abu Dhabi is cultivating an "environmentally progressive image" (Reiche, 2010b) and considering the concept of policy transfer. These choices can promote UAE's leadership role in the region and beyond.

Our analysis contributes to this growing debate and provides useful insights for the policy maker. The predicted future energy needs will largely be unfulfilled, requiring a careful consideration of energy portfolio. Yet due to technological limitations, economies of scale and prohibitive initial costs there will be a need to continue the use of energy production through fossil fuels in the medium term. The presented model shows that UAE should gradually migrate from its existing natural gas based electricity generation to include low-carbon energy sources (including renewables and nuclear), to satisfy the increasing energy demand fueled by population growth and high economic development, without incrementing the GHG emissions. This choice strongly influences the private sector and necessitates important government investments in research and development. How to finance the altering the energy portfolio is a crucial element of the Emirate's political economy, as renewable energy projects present high up-front costs of novel technologies. In addition, the UAE needs to have in place comprehensive regulations to attract investments in promoting the use of renewable energy sources and CO_2 abatement strategies. The results from the weighted GP model are comparable and consistent with the findings on the fuzzy goal programming model studied in Jayaraman et al. (2015b). An alternative policy course permitting a higher level of GHG emissions presented in scenario 2, on the one hand, can supplement the energy demand and reduce the fore-mentioned investments; on the other hand it will affect the GDP growth in the long run as increased emission implies significant economic, population health and abatement costs. Indeed, it has been clearly articulated that carbon intensive energy sources can cause premature deaths and illness, leading to substantial deterioration in public health at significant costs than often assumed. The model presented in this paper can be extended to include additional sustainability criteria on: (i) effective water resources management to study energy-water nexus, (ii) solid waste management and its impact on energy savings and GHG emissions, (iii) energy savings associated with recycling efforts to analyze interconnected challenges and opportunities in sustainable, social and economic development.

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