A fuzzy goal programming model to analyze energy, environmental and sustainability goals of the United Arab Emirates

Raja Jayaraman · Danilo Liuzzi · Cinzia Colapinto · Tufail Malik

Abstract Goal programming models offer an analytical framework to study multi-criteria problems involving several conflicting objectives. Real world problems often involve impre-cise information, which makes fuzzy goal programming (FGP) models the most attractive choice. In this paper, we propose an FGP 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 United Arab Emirates. The model offers valuable insights to decision makers for strategic planning and investment allocations towards sustainable development. We demonstrate the validity and applicability of the model through a numerical example.

1 Introduction

The United Arab Emirates (UAE) Vision 2021 highlights an ambition to attain a ‘competitive and resilient economy’ and a ‘sustainable environment’. Since its inception in 1971, the nation has seen a tremendous economic and civic development at an unprecedented pace. Such progress happens hand in hand with a remarkable rise in energy demand and an ever-growing responsibility towards the ecological footprint and environmental preservation. In

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recent years, electricity demand has grown at 9 % (Kazim 2007), making the UAE the world's 10th largest per capita electricity consumer (Mokri et al. 2013). The electricity demand in the country has grown from 38.6 TWh in 2000 to 79.5 TWh in 2009, to 90.6 TWh in 2010, with an average annual increase rate of about 8.8 % during the last decade (Mokri et al. 2013). Between the years 2006–2011, the annual increase in the electricity demand (10.8 %) closely followed the trend in annual population growth of 11 % during the same period (Mokri et al. 2013). Apart from industrial usage, this increase in the demand is overwhelmingly dominated by the commercial and residential sectors, mainly due to cooling loads in the buildings, geographically located in one of the hottest regions of the world.

Power generation in the UAE relies mainly on fossil fuels (Kazim 2007). Gas and steam turbines are the major generators, with the former types dominant. For instance, in the years 2006–2011, the Federal Electricity and Water Authority's generation capacity was based on 91–100 % using gas turbines (Mokri et al. 2013). On the other hand the countrywide electricity and water production in 2009 utilized about 45 % of the natural gas produced (Mokri et al. 2013). The UAE contains about 9.3 and 4.1 % of the world's proven oil and gas reserves, respectively (Kazim 2007). Yet the high energy demand has led the country to import natural gas since 2007. Around 80 % of oil produced in the UAE was exported in 2009, and 8 % consumed locally (Mokri et al. 2013). In the year 2011, the UAE population (which is 0.1 % of world's population) consumed 0.8 % of oil produced worldwide; this high local consumption drove the production to 3.32 million barrels of oil per day which is about 3.8 % of oil produced worldwide in 2011 (Mokri et al. 2013).

An almost total dependence on fossil–fuel based energy generation naturally leads to the environmental concerns, including production of CO_2, SO_2, other greenhouse gases and particulate matter. Water desalination plants are another major contributor to greenhouse gas (GHG) emissions and air pollution (DeFelice and Gibson 2013), which is a direct consequence of increased energy demand and consumption, furnished through a 100 % fossil–fuel based energy generation capacity (Mokri et al. 2013). The UAE's CO_2 emissions increased from 60.8 Mt in 1990 to 146.9 Mt in 2008 (Kazim 2007). Of these emissions, more than 50 % were contributed by the power sector in 2008 (Kazim 2007). Middle East and North Africa (MENA) is regarded as the second most polluted region in the world (following South Asia), that produces highest CO_2 levels per dollar of output (Omri 2013). A recent research associates over 545 deaths per year with air pollution in the UAE (DeFelice and Gibson 2013). Though not bound by treaty on GHG emissions through a classification of a Non-Annex 1 status, the UAE voluntarily decided to sign Kyoto protocol in 2005 reaffirming to commit to reducing the GHG emissions (AlFarra and Abu-Hijleh 2012).

Financial development is strongly correlated with energy consumption and CO_2 emissions (Al-mulali and Binti Che Sab 2012). The UAE's current oil reserves constitute the world's 8th largest and represent 5.9 % of the total world's reserves (Mokri et al. 2013). Considering the currently high, yet increasing energy demand, an expected annihilation of fossil–fuel sources, and the moral obligation towards environmental footprint, it is imperative to investigate the feasibility of alternate, non-fossil fuel sources of energy venues such as wind, solar, tidal and nuclear energies. Several wind speed studies have been carried out in different regions of the UAE to assess deployment of wind turbines (Mokri et al. 2013). Though the UAE has the lowest wind energy potentials in the GCC countries (Mokri et al. 2013), this resource is still being explored. In 2009, the establishment of the Emirates Nuclear Energy Corporation was a step towards addressing the objective of meeting 25 % of the UAE's electricity demand through nuclear energy by 2020. Four plants are planned, with the first one expected to start electricity generation by the year 2017. It is hoped that this will not only provide enough electricity to meet the needs of the increasing demand, but the cost is expected to be lower than current, and in addition, will help to reduce CO_2 emissions (AlFarra and Abu-Hijleh 2012). The geographic location of the UAE and the weather conditions allow an abundance of solar irradiance and intensity to stay available for a sufficient amount of time every day and all year round. Various approaches (including artificial neural networks, ground measurements and satellite imaging) have been used to evaluate various regions of the UAE for the reception of solar energy, and different solar cell technologies have been investigated for performance. We refer the reader to Mokri et al. (2013) for a detailed description of these efforts.

Population in the UAE constitutes a diverse mix of nationalities and cultures. Over 80 % of the total population of 9.2 million (Labor Migration in UAE 2013) are expats, with the market heavily dependent on foreign labor for development and future growth. The objective of the current paper is to develop a fuzzy goal programming (FGP) model aimed to optimize resource allocation in order to achieve economic growth (G1), energy consumption (G2), environment (G3) and number of employees (G4) goals necessary to meet an economic sustainability by the year 2030. It is interesting to note that the four identified goals are conflicting. High economic growth requires an increased use of labor resources and that of energy, in turn leading to high levels of pollution. Multi-criteria decision making techniques are popular in sustainable energy management and provide solutions to the problems involving conflicting and multiple objectives.

Goal programming (GP) is a methodology widely applied to multi-criteria decision problems arising in several areas such as manufacturing, production planning, marketing, supply chains, healthcare, management science and environment and energy, just to name a few. The origins of the method can be traced to an application of executive compensation by Charnes et al. (1955) with a more formal introduction by Charnes and Copper (1961). GP models can be viewed as a generalization of linear programming which is aimed at meeting the quantified goals as closely as possible, where the decision maker (DM) tries to minimize the distances between the goals and the actual values of the criteria or objective functions faced in the decision procedure. A goal is a numerical level that is the target level the DM desires to achieve, relative to the criterion. The distance metric-based variants of GP include lexicographic, weighted, and Chebyshev GP (Jones and Tamiz 2010). The decision variable and goal-based variants include fuzzy, integer, binary, and fractional GP (Jones and Tamiz 2010).

The rest of the paper is structured as follows. In Sect. 2 we discuss the related literature on multi-criteria methods including FGP models used in economic, energy and environmental problems. In Sect. 3 we present the FGP methodology. Section 4 focuses on data collection methods and analysis, and Sect. 5 introduces the FGP model and presents the numerical validation. In Sect. 6 we present the conclusions of the model and highlight the implications for policy planning and strategic resource allocation to achieve sustainability goals by the year 2030.

2 Related literature

Energy policy plays a key role in sustainable development. During the past decades a variety of energy resources allocation models (dealing with quantitative and qualitative criteria) have been developed and studied. Policy makers deal with energy-related issues and how they interact or affect economic growth and environmental quality. Indeed, multi-criteria models based on weighted averages, priority setting, outranking, fuzzy principles and their combinations have been employed for energy planning decisions. In particular, many researchers deal with the planning of sustainable electricity or energy generation and CO_2 mitigation (EGCM) infrastructure design under uncertainty. Interval mathematical programming and stochastic mathematical programming models are proposed to the design of the EGCM infrastructure under uncertainties.

Kiker et al. (2005) present a review of the available literature and provide recommendations for applying multi-criteria decision analysis techniques in environmental projects. Recent contributions in this area confirm the relevance of multi-criteria approach. Han et al. (2012) propose a multi-objective optimization model to determine available technologies to produce electricity and treat CO_2 for maximizing the expected profits and minimizing the financial risk of handling uncertain environments. Arnette and Zobel (2012) discuss a multi-objective linear programming model to be used to determine the optimal mix of renewable energy sources and existing fossil fuel facilities balancing the corresponding GHG emissions. The extant literature has shown the importance of fuzzy techniques to deal with multi-criteria environmental decision making. For instance, Agrawal and Singh (2001) analyze a fuzzy multi-objective energy allocation problem for cooking use in households. Borges and Antunes (2003) develop a fuzzy multiple objective decision support model to study the relationships between the economy and the energy sector on a national level. A fuzzy linear programming model is formulated by Sadeghi and Hosseini (2006) for the optimization of supply energy system of Iran. Kazemi et al. (2011) allocate optimally, to each end-use, a certain amount of energy to be supplied by a given resource in Iran with an emphasis on GHG reduction using neural networks and fuzzy linear regression methods. Among all different multi-criteria decision making techniques a crucial role has been played by GP and its variants. Ramathan and Ganesh (1995a, b) incorporate nine quantitative and three qualitative criteria (representing the energy–economy–environmental system) and combine them using GP and the Analytic Hierarchy Process. Mezher et al. (1998) formulate a multi-objective Lexicographic GP model to allocate specific energy resources to the various household end-uses in Lebanon. The energy allocation process is looked at from two points of view: economy (costs, efficiency, energy conservation and employment generation) and environment. André et al. (2009) propose a methodology based upon Simonian satisficing logic implemented though a GP model that allows to address the joint design of macroeconomic and environmental policies.

The high level of uncertainty involved in the real world energy planning problems implies that exact input data is impossible to acquire. Hence FGP approach is suited well to handle energy, environmental and economic planning and provide better solution to decision maker(s). In literature there are numerous contributions. Lee et al. (2007, 2008) aim to evaluate the effects of carbon taxes on different industries, and simultaneously find an optimal carbon tax scenario through a FGP approach, integrated with grey prediction and input–output theory. Ghosh et al. (2010) introduce a Multi-objective Fuzzy Non-linear GP model in order to optimize the resources, to control wastage and auxiliary consumption and to maximize sales and profit. Daim et al. (2010) develop a FGP model to create a renewable energy portfolio with the objective of responding to a 25 % of the electricity demand by renewable resources by 2025 in Oregon, USA. Jinturkar and Deshmukh (2011a, b) introduce a fuzzy mixed integer GP model for rural cooking and heating energy planning in Central India. The model considers the trade-off between socio-economic and environmental issues related to cooking and heating energy. The FGP model presented by Bilbao-Terol et al. (2012) deals with an optimal portfolio selection problem that takes into account both financial and social, environmental and ethical (SEE) criteria. Pal and Kumar (2013) present a linear GP method to solve thermal power generation and dispatch problems with interval data uncertainty. Balaman and Selim (2014a, b) deal with a multi-objective optimization problem of biomass to energy supply chains in an uncertain environment using different FGP approaches to solve their model.

In our paper we contribute to the above extant literature by applying a FGP model that integrates optimal resource allocation to simultaneously satisfy prospective goals on economic development, energy consumption, workforce, and GHG emission reduction in the UAE.

3 Fuzzy goal programming methodology

Charnes et al. (1955) presented the first formulation of a GP model that has been widely applied to several real world problems in the last six decades (Aouni and La Torre 2010; Aouni et al. 2013, 2014; Charnes and Cooper 1952, 1959; Lee 1973; Lee and Nicely 1974; Romero 1991). The simplicity in modeling, ease of understanding and flexibility to use commercial mathematical programming software such as Lingo and CPLEX make GP models quite attractive.

Formally, a standard GP model can be presented as follows:

$$\begin{aligned} &\text{Min Z} = \sum_{i=1}^{p} \left(\delta_i^+ + \delta_i^-\right) \\ &\text{subject to:} \\ &\quad f_i\,(x) + \delta_i^- - \delta_i^+ = g_i\ (\forall\, i \in I); \\ &\quad x \in E; \\ &\quad \delta_i^-, \delta_i^+ \geq 0\ (\forall\, i \in I)\,. \end{aligned} \tag{1}$$

where δ_i^+ and δ_i^- are, respectively, the positive and the negative deviations with respect to the goals g_i, $i = 1, \ldots, p$ and E is the feasible set for the input variables x (the standard hypothesis is the compactness of E). The function $f_i\,(x)$ represents the ith criterion in the set I of the criteria taken into account.

Often the objectives, constraints, and other mathematical relations involved in an optimization problem are not crisp and are expressed vaguely. Furthermore, the DM may only be interested in improving the values of the objective functions to reach the aspiration levels—which may be "vaguely" defined—as closely as possible. The FGP model is an alternative formulation of the GP model and was introduced in early 1980s based on fuzzy set theory presented by Zadeh (1965). This fundamental paper paved the way to the following diffused utilization of the concept in determining optimal solutions in multi-criteria decision making contexts. Bellman and Zadeh (1970) applied fuzzy sets to different decision-making contexts. Zimmerman (1976, 1978) introduced a fuzzy linear programming model with both single and multiple objectives. Narsimhan (1980) proposed a FGP technique for modelling the fuzziness related to the aspiration levels. Yang et al. (1991) formulated a FGP with a nonlinear membership function. Energy–economy planning and environmental decision-making present fuzzy characterizations in terms of objectives and constraints and, as shown in Sect. 2, there exist some FGP applications.

Following the definition of Zadeh (1965), the idea of a fuzzy set is an extension of the classical definition of a set. In classical set theory, each element of a universe X either belongs to a set A or not, whereas in fuzzy set theory an element belongs to a set A with a certain degree of membership. A fuzzy subset A of X is defined through a membership function $\mu_x(A)$ which expresses the degree of membership of x to A. A fuzzy set A in X is thus uniquely characterized by its membership function $\mu_x(A)$, which associates with each point in X a nonnegative finite real number that usually belongs to the interval [0, 1]. Thus the value of $\mu_x(A)$ closer to 1 implies the higher degree of 'belongingness' of x to A.

Given a set of L objective functions F_l, a general FGP model with integer variables can be presented as follows: Find x such that

$$\begin{array}{ll} F_l(\mathrm{x}) \cong \tilde{F}_l, & l = 1 \ldots \mathrm{L}, \\ g_j(x) \leq a_j, & j = 1 \ldots J, \\ h_k(x) = b_k, & k = 1 \ldots K, \\ x_i \geq 0 \text{ and integer}, & i = 1 \ldots \mathrm{N}, \end{array} \tag{2}$$

where $F_l(x)$ is the lth objective function, $g_j(x)$ is the jth inequality constraint, $h_k(x)$ is the kth equality constraint, $\tilde{F}_l$ is the lth fuzzy goal.

To indicate the fuzziness of the objective we use the symbol '$\cong$'. It is a way to describe, in a formal mathematical framework, the notion of approximation: the DM will accept values slightly greater than (or less than) $\tilde{F}_l$ up to a fixed tolerance Δ_l. The jth system constraint $g_j(x) \leq a_j$ and the kth system constraint $h_k(x) = b_k$, define the feasible set. As proposed by Yang et al. (1991), in the remainder of the paper we consider a triangular membership function $\mu_{[F_l(x)]}$ for the lth fuzzy goal. There are several different types of membership functions, but $\mu_{[F_l(x)]}$ (defined below and illustrated in Fig. 1) allows for an easier definition of the maximum and minimum limit of tolerance of each fuzzy goal with respect to its central value.

$$\mu_{[F_l(x)]} = \begin{cases} \frac{F_l(x) - F_l^{MIN}}{F_l^{GOAl} - F_l^{MIN}} & \text{if } F_l^{MIN} \leq F_l(x) \leq F_l^{GOAL} \\ \frac{F_l^{MAX} - F_l(x)}{F_l^{MAX} - F_l^{GOAl}} & \text{if } F_l^{GOAl} \leq F_l(x) \leq F_l^{MAX} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

where, F_l^{MIN} is a minimum limit of tolerance for $\tilde{F}_l$, F_l^{MAX} is a maximum limit of tolerance for $\tilde{F}_l$, F_l^{GOAl} is the average between F_l^{MIN} and F_l^{MAX}.

It is worth emphasizing that when it is reasonable to suppose that the aspiration levels (goals) are precise and deterministic, the standard GP formulation can be applied. Yet there exist many decision-making situations where the DM is not able to define the value of each goal precisely. In such cases the use of fuzzy goals appears to be more realistic and related to

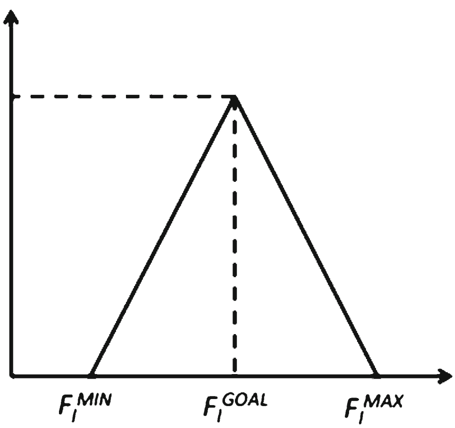

Fig. 1 The triangular membership function

the uncertainty of the objectives. In FGP the goals are considered to be represented by fuzzy sets whose membership functions provide the satisfaction degree regarding the achievement of targets.

The FGP model with integer variables can be formulated as follows (Yang et al. 1991):

$$
\begin{aligned}
&\text{Max} \quad \lambda \\
&\text{Subject to} \quad \left.\begin{array}{l} \lambda \leq \frac{F_l(x)-F_l^{MIN}}{F_l^{GOAl}-F_l^{MIN}} \\ \lambda \leq \frac{F_l^{MAX}-F_l(x)}{F_l^{MAX}-F_l^{GOAl}} \end{array}\right. \quad l = 1, \ldots, L \\
&g_j(x) \leq a_j, \quad j = 1, \ldots, J \\
&h_k(x) = b_k, \quad k = 1, \ldots, K \\
&x_i \geq 0 \text{ an integer.}
\end{aligned}
\tag{4}
$$

4 Data collection and analysis

In this section we identify the data collection methods and assumptions for goals in our FGP model, identifying the sources of data and any assumptions that were used to estimate the unknowns. Sectorial input–output tables are periodically published by several countries to enable policy planning and analysis. It is necessary to establish the relationship between the key economic sectors and their relative contribution to GDP, energy use, pollution and workforce. In this paper we have used the following eight important sectors as decision variables for the model contributing to the economy of the UAE: (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). The choice of these decision variables are in agreement with existing sources of literature. Vellinga (2006) created an eight-sector social accounting matrix (SAM) for the UAE economy that captures the economic flows, and is an important tool for macroeconomic modelling. We use the same eight sectors identified by Vellinga (2006) in our FGP model. We refer the readers to Narayanan et al. (2012) for more details on constructing SAM for several countries. Obtaining sectorial data was both difficult and challenging. The GDP contribution and number of employees in each sector was obtained from the UAE Ministry of Economy's Annual Economic Report (2012). The population demographics of the UAE present a diverse mix of nationalities and the UAE citizens. In 2013, the total population in UAE was approximately 9.2 million of which 7.8 million were expatriates (UAE National Bureau of Statistics 2011). To sustain the high economic growth and standard of living, UAE is heavily reliant on expatriate labor force (Labor Migration in UAE 2013). Data on electricity consumption was obtained from the International Energy Agency (IEA 2011). IEA data provided electricity consumption in four broad categories, (a) residential, (b) industrial (c) commercial and public services, (d) others non-specified categories. The data obtained from IEA did not provide sector-specific estimates for electricity consumption, so we estimated the percentile contribution of each sector relative to GDP and used it as a measure of disaggregation to obtain sector specific estimates for electricity consumption. Estimates on GHG emissions were obtained from the Third National Communication under the UNFCCC (United Nations Framework Convention on Climate Change 2012). The total GHG emissions in the year 2005 were 174,357 Giga grams (Gg) of CO_2 equivalent. Energy related activities contributed the largest to GHG emissions at 153,833 Gg, followed by 9426 Gg due

Table 1 Total GHG emission (in Gg) in the UAE, 2005 (*Source*: UNFCCC 2012)

GHG sources and sinks	CO_2 equivalent	CO_2	CH_4	N_2O	NOX	CO	NMVOC	SO_2
Energy	153833	128824	1011	12	330	491	27	10346
Industrial processes	9426	8629	0	0	2	207	37	9
Solvent and other product use	0	0	0	0	0	0	0	0
Agriculture	3976	0	75	8	0	0	0	0
Land use change and forestry	−13223	−13223	0	0	0	0	0	0
Waste	7122	0	339	0	0	0	0	0
Net emissions	161134	124230	1425	20	332	698	64	10355

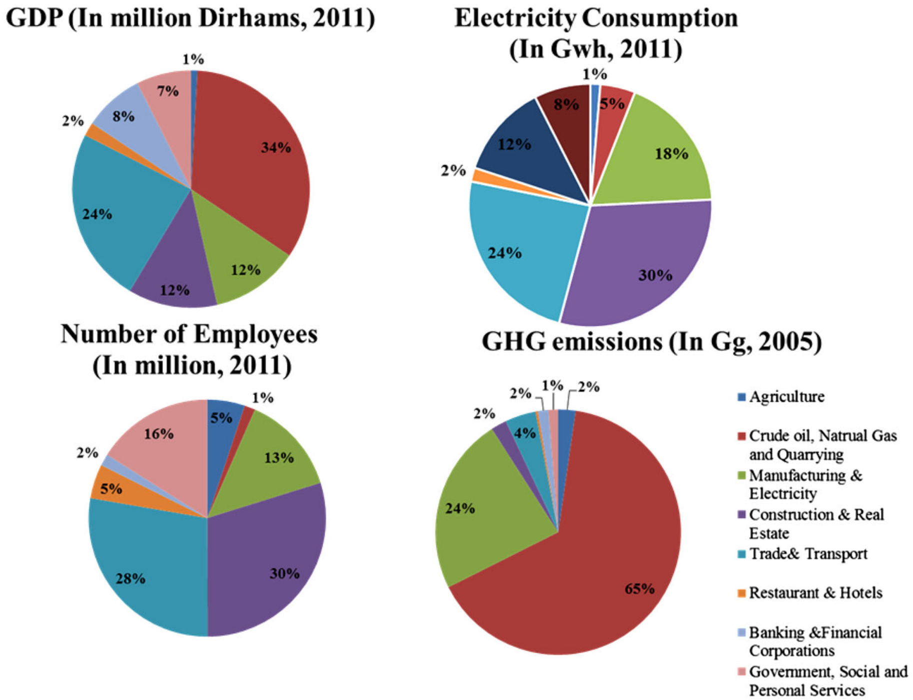

Fig. 2 Percentage contribution of the eight chosen sectors given in Table 3

to industrial activity, 7122 Gg due to waste and 3976 Gg due to agriculture. Sequestration due to forestry and land use yielded 13,233 Gg. Table 1 summarizes the sources of various GHG emissions. In our analysis we did not discount CO_2 sequestration through land use and forestry.

Figure 2 provides the information on percentage contribution of the eight decision variables relative to the four identified goals. Assuming reasonable growth trends for the four identified goals future projections for the year 2030 are presented in Table 2.

Table 3 provides the estimates of the sector-wise contribution with respect to each goal used in the FGP model. Note that the projected numbers for the goals are imprecise estimates that will be transformed to fuzzy values in solving the model.

Table 2 Projected values for the identified goals by the year 2030

Goal by year 2030	Value	Growth rate (%)
GDP growth (G1)	2725 Billion	7
Electricity consumption (G2)	286980 Gwh	8
GHG emissions (G3)	284739 Gg	2
Number of employees (G4)	9452000	3.75

Table 3 Sectorial contribution of identified goals

Decision variable	Sector	GDP per capita[a]	Electricity consumption per capita[b]	GHG emissions per capita[c]	Number of employees (in thousands, year 2010)[a]
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 and electricity	0.18134206	0.02502291	0.06629133	611000
x_4	Construction and real estate	0.08385650	0.01873543	0.00267227	1338000
x_5	Trade and transport	0.17690457	0.01614274	0.00627506	1247000
x_6	Restaurant and hotels	0.08095238	0.00738571	0.00258095	210000
x_7	Banking and 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:
[a] UAE Ministry of Economy Annual Economic Report, UAE National Bureau of Statistics
[b] International Energy Agency
[c] Third communication to United Nations framework convention on climate change

5 Model and numerical validation

First we enumerate the criteria discussed in the previous section:

F_1: GDP (in million AED),
F_2: Electricity consumption (in Gwh),
F_3: Emissions (in Gg CO_2 equivalent),
F_4: Number of employees (in Thousands).

As highlighted in the previous paragraph, the selected goals are reasonable projections. However there is a degree of uncertainty inherent in the procedure to arrive at exact goal values, so we use the FGP approach. A membership function remains to be chosen. By definition, the only condition a membership function must satisfy is that its value ranges between 0 and 1. The function itself can be an arbitrary curve. We chose the triangular membership function because of its ease in defining the maximum and minimum limit of tolerance of each fuzzy goal with respect to its central value.

Let F_l^{GOAl}, $l = 1, 2, 3, 4$, denote the average value of the triangular membership function defined around each goal. Each criterion or objective function F_i is the sum of eight contributions, one per sector:

$$F_l = \sum_{i}^{8} a_{il} x_i$$

The number of employees in the lth sector contributes to the total amount of the objective through a coefficient a_{il} which describes the per capita contribution of each employee to that objective. For example, a_{11} is the per capita GDP produced by an employee in the agricultural sector. The overall contribution of the agricultural sector is $a_{11}x_1$. These coefficients represent the ratio between the total contribution of the lth sector and the total amount of workers of that sector, at the most recent available evaluation. The DM acts on the allocation of employees among the various sectors. We use triangular membership functions $\mu_{[F_l(x)]}$, and define F_l^{MIN} and F_l^{MAX}. These thresholds are chosen to be at a fixed tolerance $\Delta_l = tol{*}F_l^{GOAl}$ above and below the ideal goals. Referring to the last column of Table 2, these eight sectors have $x_{i,2010}$ workers, with $i = 1, 2, \ldots, 8$. It is reasonable to assume that the number of employees will increase in each sector, since the UAE is experiencing a strong and positive economic growth for decades. Hence we impose the constraint that the optimal solution preserves the current number of jobs:

$$x_i \geq x_{i,2010}, \quad i = 1, 2, \ldots 8.$$

We define auxiliary variables λ_1, λ_2, λ_3 and λ_4 related to each goal. The definition relies on the fact that the higher the value of λ_i the closer the value of the ith membership function is to its maximum value, 1, the most desirable outcome. It is possible to use just one auxiliary variable λ for all the four membership functions, at the expense of being limited by the least attainable target.

The model is stated as:

$$\begin{aligned}
&\text{Maximize } \lambda = \sum_{l=1}^{4} \lambda_l \\
&\text{Subject to} \\
&\quad \lambda \leq \mu_{[F_1(x)]} \\
&\quad \lambda \leq \mu_{[F_2(x)]} \\
&\quad \lambda \leq \mu_{[F_3(x)]} \\
&\quad \lambda \leq \mu_{[F_4(x)]} \\
&\quad x_i \geq x_{i,2010}, \quad i = 1, 2, \ldots 8.
\end{aligned} \tag{5}$$

Specifically,

$$\begin{aligned}
&\text{Maximize } \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 \\
&\text{Subject to} \\
&\lambda_1 \leq \left\{ \begin{array}{ll} \frac{\sum_i^8 a_{i1}x_i - F_1^{MIN}}{F_1^{GOAl} - F_1^{MIN}} & \text{if } F_1^{MIN} \leq \sum_i^8 a_{i1}x_i \leq F_1^{GOAl} \\ \frac{F_1^{MAX} - \sum_i^8 a_{i1}x_i}{F_1^{MAX} - F_1^{GOAl}} & \text{if } F_1^{GOAl} \leq \sum_i^8 a_{i1}x_i \leq F_1^{MAX} \end{array} \right\}
\end{aligned}$$

$$\lambda_2 \leq \left\{ \begin{array}{ll} \frac{\sum_i^8 a_{i2}x_i - F_2^{MIN}}{F_2^{GOAl} - F_2^{MIN}} & \text{if } F_2^{MIN} \leq \sum_i^8 a_{i2}x_i \leq F_2^{GOAl} \\ \frac{F_2^{MAX} - \sum_i^8 a_{i2}x_i}{F_2^{MAX} - F_2^{GOAl}} & \text{if } F_2^{GOAl} \leq \sum_i^8 a_{i2}x_i \leq F_2^{MAX} \end{array} \right\}$$

$$\lambda_3 \leq \left\{ \begin{array}{ll} \frac{\sum_i^8 a_{i3}x_i - F_3^{MIN}}{F_3^{GOAl} - F_3^{MIN}} & \text{if } F_3^{MIN} \leq \sum_i^8 a_{i3}x_i \leq F_3^{GOAl} \\ \frac{F_3^{MAX} - \sum_i^8 a_{i3}x_i}{F_3^{MAX} - F_3^{GOAl}} & \text{if } F_3^{GOAl} \leq \sum_i^8 a_{i3}x_i \leq F_3^{MAX} \end{array} \right\}$$

$$\lambda_4 \leq \left\{ \begin{array}{ll} \frac{\sum_i^8 a_{i4}x_i - F_4^{MIN}}{F_4^{GOAl} - F_4^{MIN}} & \text{if } F_4^{MIN} \leq \sum_i^8 a_{i4}x_i \leq F_4^{GOAl} \\ \frac{F_4^{MAX} - \sum_i^8 a_{i4}x_i}{F_4^{MAX} - F_4^{GOAl}} & \text{if } F_4^{GOAl} \leq \sum_i^8 a_{i4}x_i \leq F_4^{MAX} \end{array} \right\}$$

$$x_i \geq x_{i,2010}, \quad i = 1, 2, \ldots 8. \tag{6}$$

5.1 Validation and discussion

In order to numerically validate the proposed model, we consider the data and objectives discussed in Table 2 and the goals for each criterion, $F_1^{GOAl} = 2724850$, $F_2^{GOAl} = 286980$, $F_3^{GOAl} = 284739$ and $F_4^{GOAl} = 9452000$. The tolerance is set as $tol = 0.3$. Taking into account the chosen tolerance and triangular membership function, the four fuzzy goals are given by:

$$\mu_{[F_i(x)]} = \left\{ \begin{array}{ll} \left[\frac{\mathrm{F}_i(x) - (1-\mathrm{tol})*F_i^{GOAl}}{F_i^{GOAl} - (1-\mathrm{tol})*F_i^{GOAl}}\right], & \text{if } (1-\mathrm{tol})*F_i^{GOAl} \leq F_i(x) \leq F_i^{GOAl} \\ \left[\frac{(1+\mathrm{tol})*F_i^{GOAl} - \mathrm{F}_l(x)}{(1+\mathrm{tol})*F_i^{GOAl} - F_i^{GOAl}}\right], & \text{if } F_i^{GOAl} \leq F_i(x) \leq (1+\mathrm{tol})*F_i^{GOAl} \\ 0, & \text{otherwise} \end{array} \right. \tag{7}$$

where $F_i^{MIN} = (1 - tol)*F_i^{GOAl}$ and $F_i^{MAX} = (1 + tol)*F_i^{GOAl}$.
The detailed model is given by:

Maximize λ

Subject to:

$$\begin{aligned} \lambda \leq\ & (0.03521739x_1 + 4.69696970x_2 + 0.18134206x_3 + 0.08385650x_4 \\ & + 0.17690457x_5 + 0.08095238x_6 + 1.05138889x_7 + 0.09569444x_8 \\ & -1907395)/(2724850 - 1907395) \end{aligned}$$

$$\begin{aligned} \lambda \leq\ & (3542305 - (0.03521739x_1 + 4.69696970x_2 + 0.18134206x_3 \\ & + 0.08385650x_4 + 0.17690457x_5 + 0.08095238x_6 + 1.05138889x_7 \\ & + 0.09569444x_8))/(3542305 - 2724850) \end{aligned}$$

Table 4 Results of the FGP model with tolerance = 0.3

Variable	Value	Variable	Value	Variable	Value	Variable	Value
λ_1	5.61E−08	G1	2724850	x_1	230000	x_5	3516587
λ_2	3.52E−06	G2	286980	x_2	136704	x_6	210000
λ_3	0.6371894	G3	284739	x_3	611000	x_7	72000
λ_4	1	G4	9452000	x_4	1338000	x_8	3337709

$$\lambda \leq (0.00479^{*}\,\mathrm{x}_1 + 0.05912x_2 + 0.02502x_3 + 0.1874x_4 + 0.01614x_5 + 0.00739x_6 + 0.14510x_7 + 0.00872x_8 - 200886)/(286980 - 200886)$$

$$\lambda \leq (373074 - (0.00479^{*}\,\mathrm{x}_1 + 0.05912x_2 + 0.02502x_3 + 0.1874x_4 + 0.01614x_5 + 0.00739x_6 + 0.14510x_7 + 0.00872x_8))/(373074 - 286980)$$

$$\lambda \leq (0.01728696x_1 + 1.71707576x_2 + 0.06629133x_3 + 0.00267227x_4 + 0.00563352x_5 + 0.00258095x_6 + 0.03349306x_7 + 0.00305000x_8 - 199317.3)/(284739 - 199317.3)$$

$$\lambda \leq (370160.7 - (0.01728696x_1 + 1.71707576x_2 + 0.06629133x_3 + 0.00267227x_4 + 0.00563352x_5 + 0.00258095x_6 + 0.03349306x_7 + 0.00305000x_8))/(370160.7 - 284739)$$

$$\lambda \leq (x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 - 9452000)/(9452000 - 6616400)$$

$$\lambda \leq (12287600 - (x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8))/(12287600 - 945200)$$

$$x_1 \geq 230000;$$
$$x_2 \geq 66000;$$
$$x_3 \geq 611000;$$
$$x_4 \geq 1338000;$$
$$x_5 \geq 1247000;$$
$$x_6 \geq 210000;$$
$$x_7 \geq 72000;$$
$$x_8 \geq 720000;$$

The model was solved using LINGO 14 and results are presented and discussed below.

As we see in Table 4, the value of λ_1 and λ_2 are very small, but non-zero. This means that the values of the first two objectives belong to the non-zero interval of the membership function. Under the triangle, the obtained values of GDP and electricity consumption cannot be fully satisfied. As for the reduction of GHG emission, the level of membership is considerably greater than zero, meaning that the goal can be discretely satisfied. The goal is completely attained in the case of the number of employees denoted by the value of the membership function as one. The output from the FGP model can be interpreted as follows.

5.1.1 GDP growth

The model suggests that the achievement of goals set for the economic growth by the year 2030 will not be possible without additional measures to generate sources of revenue. This is underscored by the distinctly low value of λ_1. Creating a sustainable knowledge-based economy, as is characterized in the Abu Dhabi Economic Vision 2030, is essential to help achieve the envisioned economic future.

5.1.2 Electricity consumption

The low value of λ_2 signifies the need for extraordinary policy measures towards the electricity consumption to fulfill the incredibly high demand. The model thus proposes, as in the case of the economic growth, that the goal related to meeting the energy consumption by the year 2030 will not be attained without additional efforts to diversify sources of electricity generation. Alternate and renewable energy sources are essential to cope with the growing consumption. This is consistent with the current focus and efforts on additional investments made towards clean and renewable sources of energy to satisfy the growing energy concerns.

5.1.3 GHG emissions

With respect to achieving reduction in GHG emissions target by 2030 a sustained effort on promotion and use of cleaner sources of energy and CO_2 capture and sequestration efforts can drastically reduce the CO_2 emissions. The effectiveness of the aggressive policy currently in place is endorsed by the model, with possibly some minor additional measures needed (as the value of λ_3 is reasonably high, but still not unity).

5.1.4 Number of employees

The value of λ_4 is equal to unity, which reassures that the goal to preserve the number of employees in the UAE is perfectly attainable. Perhaps an increase in the number of employees may be required to maintain a strong GDP growth in the coming decades.

The above inferences, especially those relevant to energy and environment, are in line with the conclusions of polynomial goal programming (PGP) model developed in Jayaraman et al. (2015) to study the effects of energy and emission in the UAE. The common policy-specific message between the two models is the focus on the diversification of energy portfolio by adding alternate energy sources, and a strong push towards lowering the domestic GHG emissions. The FGP model reinforces the PGP model by providing further mathematical justification and reasoning for future investments and strategic planning towards achieving sustainable development goals in the UAE by 2030. Additionally, the collective attainment of all four goals considered in the FGP model seems viable.

6 Conclusions

Environmental decisions are often complex and multi-faceted and involve value trade-offs and uncertainty. In this paper we developed a FGP model that integrates optimal resource allocation to simultaneously satisfy prospective goals on economic development, energy consumption, workforce, and GHG emission reduction by the year 2030 applied to key economic sectors of the UAE. The model offers a quantitative and mathematical justification for additional investments to change the portfolio of energy mix in the UAE. The analysis presented in our model highlights the significance of further exploration of alternate (green) energy sources. An implementation of strategies in this direction will impact the GDP in a positive manner, enhancing the weak level of membership in the corresponding objective function. The recent and current developments in nuclear power plants (Barakah), harnessing wind energy, concentrated solar energy (Shams 1), and smart city (MASDAR) serve as a testimony to the leadership role of the UAE towards achieving a sustainable development by the year 2030. As future extension of this study we plan to include a comparative analysis of energy, environmental and economic goals for several gulf cooperating council (GCC) nations.

Acknowledgements This work was supported by funding from Office of Research Support, Internal Research Fund (KUIRF)—Grant Number 210032, Khalifa University. This work has been carried out and completed during research visits of Cinzia Colapinto at Khalifa University.

References

Agrawal, R. K., & Singh, S. P. (2001). Energy allocation for cooking in UP household (india) a fuzzy multi-objective analysis. *Energy Conversion and Management*, *42*, 2139–2154.

AlFarra, H. J., & Abu-Hijleh, B. (2012). The potential role of nuclear energy in mitigating CO_2 emissions in the United Arab Emirates. *Energy Policy*, *42*, 272–285.

Al-mulali, U., & Binti Che Sab, C. N. (2012). The impact of energy consumption and CO_2 emission on the economic and financial development in 19 selected countries. *Renewable and Sustainable Energy Reviews*, *16*(7), 4365–4369.

André, F. J., Cardenete, M. A., & Romero, C. (2009). A goal programming approach for a joint design of macroeconomic and environmental policies: A methodological proposal and an application to the Spanish economy. *Environmental Management*, *43*, 888–898.

Aouni, B., & La Torre, D. (2010). A generalized stochastic goal programming model. *Applied Mathematics and Computation*, *215*, 4347–4357.

Aouni, B., Colapinto, C., & La Torre, D. (2013). A cardinality constrained stochastic goal programming model with satisfaction functions for venture capital investment decision making. *Annals of Operations Research*, *205*(1), 77–88.

Aouni, B., Colapinto, C., & La Torre, D. (2014). Portfolio management through goal programming: State-of-the-art. *European Journal of Operations Research*, *234*, 536–545.

Arnette, A., & Zobel, C. W. (2012). An optimization model for regional renewable energy development: Review article. *Renewable and Sustainable Energy Reviews*, *16*(7), 4606–4615.

Balaman, Ş. Y., & Selim, H. (2014a). Multiobjective optimization of biomass to energy supply chains in an uncertain environment. *Computer Aided Chemical Engineering*, *33*, 1267–1272.

Balaman, Ş. Y., & Selim, H. (2014b). A fuzzy multiobjective linear programming model for design and management of anaerobic digestion based bioenergy supply chains. *Energy*, *74*, 928–940.

Bellman, R. E., & Zadeh, L. A. (1970). Decision making in a fuzzy environment. *Management Sciences*, *17*, B141–B164.

Bilbao-Terol, A., Arenas-Parra, M., & Cañal-Fernández, V. (2012). A fuzzy multi-objective approach for sustainable investments. *Expert Systems with Applications*, *39*(12), 10904–10915.

Borges, A. R., & Antunes, C. H. (2003). A fuzzy multiple objective decision support model for energy-economy planning. *European Journal of Operational Research*, *145*, 304–316.

Charnes, A., & Cooper, W. W. (1952). Chance constraints and normal deviates. *Journal of the American Statistical Association*, *57*, 134–148.

Charnes, A., Cooper, W. W., & Ferguson, R. (1955). Optimal estimation of executive compensation by linear programming. *Management Science*, *1*, 138–151.

Charnes, A., & Cooper, W. W. (1959). Chance-constrained programming. *Management Science*, *6*, 73–80.

Charnes, A., Copper, W. W. (1961). *Management models and Industrial applications of linear programming*. New York: John Wiley & Sons Inc.

Daim, T. U., Kayakutlu, G., & Cowan, K. (2010). Developing Oregon's renewable energy portfolio using fuzzy goal programming model. *Computers and Industrial Engineering*, *59*, 786–793.

DeFelice, N. B., & Gibson, J. M. (2013). Effect of domestic water use on air pollutant emissions in Abu Dhabi, United Arab Emirates. *International Journal of Energy and Environmental Engineering*, *4*(1), 33.

Ghosh, S., Basu, S. C., & Sengupta, P. P. (2010). Improvement of financial efficiency and cost effectiveness in energy sector: A case study from Indian thermal power plant. In *ICEMT 2010–2010 international conference on education and management technology proceedings* (pp. 512–516).

Han, J.-H., Ahn, Y.-C., & Lee, I.-B. (2012). A multi-objective optimization model for sustainable electricity generation and CO_2 mitigation (EGCM) infrastructure design considering economic profit and financial risk. *Applied Energy*, *95*, 186–195.

International Energy Agency. (2011). Retrieved online http://www.iea.org/statistics/statisticssearch/report/?country=UAE&product=electricityandheat&year=2011

Jayaraman, R., La Torre, D., Malik, T., & Pearson, Y. E. (2015). A polynomial goal programming model with application to energy consumption and emissions in United Arab Emirates. In *Proceedings of 2015 international conference on industrial engineering and operations management. IEEE xplore*. ISBN: 978-0-9855497-2-5.

Jinturkar, A. M., & Deshmukh, S. S. (2011a). A fuzzy mixed integer goal programming approach for cooking and heating energy planning in rural India. *Expert Systems with Applications*, *38*(9), 11377–11381.

Jinturkar, A. M., & Deshmukh, S. S. (2011b). Optimization of energy resources for cooking and heating-A fuzzy goal programming approach. *Journal of Renewable and Sustainable Energy*, *3*(4), 043117.

Jones, D., & Tamiz, M. (2010). Case study—Aplication of goal programming in portfolio selection. Practical goal programming, International series in operations research & management science: Springer.

Kazemi, A., Mehregan, M. R., & Shakouri, H. (2011). Energy supply model for Iran with an emphasis on greenhouse gas reduction. In *Proceedings of the 41st international conference on computers & industrial engineering* (pp. 491–496).

Kazim, A. M. (2007). Assessments of primary energy consumption and its environmental consequences in the United Arab Emirates. *Renewable and Sustainable Energy Reviews*, *11*(3), 426–446.

Kiker, G., Kiker, A., Bridges, T. S., Varghese, A., Seager, T. P., & Linkov, I. (2005). Application of Multicriteria Decision Analysis in Environmental Decision Making. *Integrated Environmental Assessment and Management*, *1*(2), 95–108.

Labor Migration in UAE. (2013). Retrieved online, URL: http://www.migrationpolicy.org/article/labor-migration-united-arab-emirates-challenges-and-responses

Lee, S. M. (1973). Goal programming for decision analysis of multiple objectives. *Sloan Management Review*, *14*, 11–24.

Lee, C. F., Lin, S. J., Lewis, C., & Chang, Y. F. (2007). Effects of carbon taxes on different industries by fuzzy goal programming: A case study of the petrochemical-related industries. *Taiwan, Energy Policy*, *35*(8), 4051–4058.

Lee, C. F., Lin, S. J., & Lewis, C. (2008). Analysis of the impacts of combining carbon taxation and emission trading on different industry sectors. *Energy Policy*, *36*(2), 722–729.

Lee, S. M., Nicely, R. (1974). Goal programming for marketing decisions: A care study. *The Journal of Marketing*, *38*(1), 24–32.

Mezher, T., Chedid, R., & Zahabi, W. (1998). Energy resource allocation using multi-objective goal programming: The case of Lebanon. *Applied Energy*, *61*(4), 175–192.

Mokri, A., Aal Ali, M., & Emziane, M. (2013). Solar energy in the United Arab Emirates: A review. *Renewable and Sustainable Energy Reviews*, *28*, 340–375.

Narayanan, B. G., Aguiar, A., & McDougall, R. (2012). Global trade, assistance, and production: The GTAP 8 data base. Center for global trade analysis, Purdue University.

Narsimhan, R. (1980). Goal programming in a fuzzy environment. *Decision Sciences*, *11*, 325–336.

Omri, A. (2013). CO_2, emissions, energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models. *Energy Economics*, *40*, 657–664.

Pal, B. B., & Kumar, M. (2013). Interval goal programming for economic–environmental power generation: Dispatch problems. In *IEEE international conference on fuzzy systems 2013* (p. 6622446).

Ramathan, R., & Ganesh, L. S. (1995a). Energy resource allocation incorporating qualitative and quantitative criteria: An integrated model using goal programming and AHP. *Socio-Economic Planning*, *29*(3), 197–218.

Ramathan, R., & Ganesh, L. S. (1995b). Energy alternatives for lighting in households: An evaluation using an integrated goal programming-AHP model. *Energy*, *20*(1), 63–72.

Romero, C. (1991). *Handbook of critical issues in goal programming*. Elmsford: Pergamon.

Sadeghi, M., & Hosseini, H. M. (2006). Energy supply planning in Iran by using fuzzy linear programming approach (regarding uncertainties of investment costs). *Energy Policy*, *34*, 993–1003.

UAE Ministry of Economy-Annual Economic Report. (2012). Retrieved online: http://www.economy.ae/English/Documents/Annual%20Economic%20Report%202012-en.pdf

UAE National Bureau of Statistics. (2011). URL: http://www.uaestatistics.gov.ae/EnglishHome/CensusEN/

UAE Vision 2021. Retrieved online URL: http://www.vision2021.ae/en

United Nations Framework Convention on Climate Change. (2012). Retrieved online: http://unfccc.int/national_reports/non-annex_i_natcom/items/2979.php

Vellinga, N. (2006). Eight-sector social accounting matrix of the UAE economy, 2006, Working Paper, Economic Policy Research Unit, Zayed University.

Yang, T., Ignizio, J. P., & Kim, H.-J. (1991). Fuzzy programming with nonlinear membership functions: Piecewise linear approximation. *Fuzzy Sets and System*, *41*, 39–53.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*, 338–353.

Zimmerman, H. J. (1976). Description and optimization of fuzzy systems. *International Journal of general systems*, *2*(1), 209–215.

Zimmerman, H. J. (1978). Fuzzy programming and linear programming with several objective functions. Fuzzy Sets and Systems, *1*(1), 45–55.