

# A Fuzzy Goal Programming Model to Analyze Energy, Environmental and Sustainability Goals of the United Arab Emirates

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## Abstract

Goal programming models offer an analytical framework to study multi-criteria problems involving several conflicting objectives. Real world problems often involve imprecise 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 green house gas (GHG) emission reduction applied to key economic sectors of the United Arab Emirates (UAE). 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.

*Keywords:* Multi-criteria decision making, Fuzzy goal programming, Membership functions, Energy, Environment

## 1. Introduction

The 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 recent years, electricity demand has grown at 9% (Kazim, 2007), making the UAE the world’s 10<sup>th</sup> 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 to 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%

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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<sub>2</sub>, SO<sub>2</sub>, other greenhouse gases and particulate matter. Water desalination plants are another major contributor to 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions (Al-mulali et al., 2012). The UAE's current oil reserves constitute the world's 8<sup>th</sup> 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<sub>2</sub> 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 Cooper (1971). 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 section 2 we discuss the related literature on multi-criteria methods including FGP models used in economic, energy and environmental problems. In section 3 we present the FGP methodology. Section 4 focuses on data collection methods and analysis, and section 5 introduces the FGP model and presents the numerical validation. In section 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<sub>2</sub> 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<sub>2</sub> 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 goal programming and its variants. Ramanathan 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 through 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. Gosh 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 & profit. Daim et al. (2010) develop a FGP model to create a renewable energy portfolio with the objective of responding to a 25 percent 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 goal programming method to solve thermal power generation and dispatch problems with interval data uncertainty. Yilmaz 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 greenhouse gas (GHG) emission reduction in the United Arab Emirates.

### **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 et al., 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:

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

Where  $\delta_i^+$  and  $\delta_i^-$  are, respectively, the positive and the negative deviations with respect to the goals  $g_i$ ,  $i=1, \dots, p$  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  $i^{\text{th}}$  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 Section 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

$$\begin{aligned} F_l(x) &\cong \tilde{F}_l, & l &= 1 \dots L, \\ g_j(x) &\leq a_j, & j &= 1 \dots J, \end{aligned} \tag{2}$$

$$h_k(x) = b_k, \quad k = 1 \dots K,$$

$$x_i \geq 0 \text{ and integer, } i = 1 \dots N,$$

where

$F_l(x)$  is the  $l^{th}$  objective function,  
 $g_j(x)$  is the  $j^{th}$  inequality constraint,  
 $h_k(x)$  is the  $k^{th}$  equality constraint,  
 $\tilde{F}_l$  is the  $l^{th}$  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  $\Delta_l$ . The  $j^{th}$  system constraint  $g_j(x) \leq a_j$  and the  $k^{th}$  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  $l^{th}$  fuzzy goal. There are several different types of membership functions, but  $\mu_{[F_l(x)]}$  (defined below and illustrated in Figure 1) allows for an easier definition of the maximum and minimum limit of tolerance of each fuzzy goal with respect to its central value.

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

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  $F_l^{MAX}$

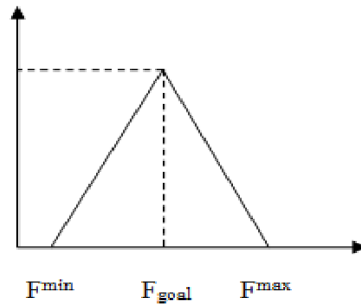


Figure 1. The triangular membership function

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 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):

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

#### 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 (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<sub>2</sub> equivalent. Energy related activities contributed the largest to GHG emissions at 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 forestry and land use yielded 13,233 Gg. Table 1 summarizes the sources and sinks of various GHG emissions. In our analysis we did not discount CO<sub>2</sub> sequestration through land use and forestry.

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

GHG Sources and Sinks	CO <sub>2</sub> Equivalent	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NOX	CO	NMVOC	SO <sub>2</sub>
Energy	153833	128824	1011	12	330	491	27	10346
Industrial Processes	9426	8629	0	0	2	207	37	9
Solvent & Other Product Use	0	0	0	0	0	0	0	0
Agriculture	3976	0	75	8	0	0	0	0
Land Use Change & 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



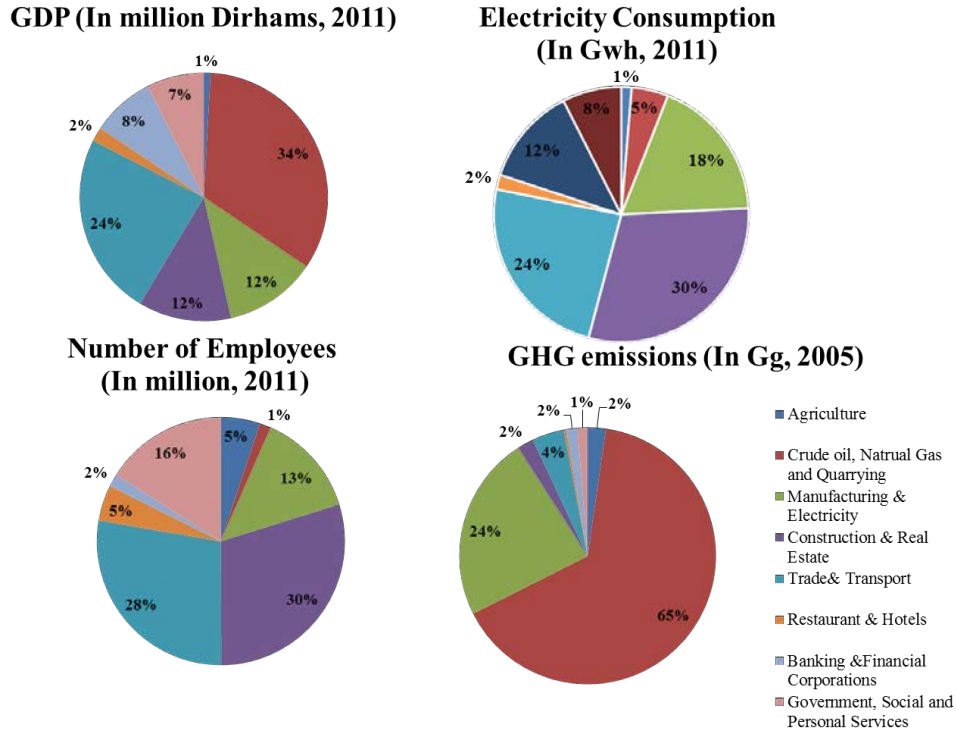


Figure 2: Percentage contribution of the eight chosen sectors given in Table 3

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

Goal by Year 2030	Value	Growth Rate
GDP growth (G1)	2,725 Billion	7%
Electricity Consumption (G2)	286,980 Gwh	8%
GHG Emissions (G3)	284,739 Gg	2%
Number of Employees (G4)	9452000	3.75%

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 3: Sectorial contribution of identified goals

Decision Variable	Sector	GDP Per Capita*	Electricity Consumption Per Capita**	GHG Emissions Per Capita†	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

† 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<sub>2</sub> 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  $l^{th}$  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  $l^{th}$  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  $i = 1, 2, \dots, 8$ . 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:

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

We define auxiliary variables  $\lambda_1, \lambda_2, \lambda_3$  and  $\lambda_4$  related to each goal. The definition relies on the fact that the higher the value of  $\lambda_i$  the closer the value of the  $i^{th}$  membership function is to its maximum value, 1, the most desirable outcome. It is possible to use just one auxiliary variable  $\lambda$  for all the four membership functions, at the expense of being limited by the least attainable target.

The model is stated as:

$$\text{Maximize } \lambda = \sum_{l=1}^4 \lambda_l$$

Subject to

$$\lambda \leq \mu_{[F_1(x)]}$$

$$\lambda \leq \mu_{[F_2(x)]}$$

$$\lambda \leq \mu_{[F_3(x)]}$$

$$\lambda \leq \mu_{[F_4(x)]}$$

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

(5)

Specifically,

$$\text{Maximize } \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4$$

Subject to

$$\begin{aligned}
\lambda_1 &\leq \left\{ \begin{array}{l} \frac{\sum_i^8 a_{i1}x_i - F_1^{MIN}}{F_1^{GOAL} - F_1^{MIN}} \quad \text{if } F_1^{MIN} \leq \sum_i^8 a_{i1}x_i \leq F_1^{GOAL} \\ \frac{F_1^{MAX} - \sum_i^8 a_{i1}x_i}{F_1^{MAX} - F_1^{GOAL}} \quad \text{if } F_1^{GOAL} \leq \sum_i^8 a_{i1}x_i \leq F_1^{MAX} \end{array} \right\} \\
\lambda_2 &\leq \left\{ \begin{array}{l} \frac{\sum_i^8 a_{i2}x_i - F_2^{MIN}}{F_2^{GOAL} - F_2^{MIN}} \quad \text{if } F_2^{MIN} \leq \sum_i^8 a_{i2}x_i \leq F_2^{GOAL} \\ \frac{F_2^{MAX} - \sum_i^8 a_{i2}x_i}{F_2^{MAX} - F_2^{GOAL}} \quad \text{if } F_2^{GOAL} \leq \sum_i^8 a_{i2}x_i \leq F_2^{MAX} \end{array} \right\} \\
\lambda_3 &\leq \left\{ \begin{array}{l} \frac{\sum_i^8 a_{i3}x_i - F_3^{MIN}}{F_3^{GOAL} - F_3^{MIN}} \quad \text{if } F_3^{MIN} \leq \sum_i^8 a_{i3}x_i \leq F_3^{GOAL} \\ \frac{F_3^{MAX} - \sum_i^8 a_{i3}x_i}{F_3^{MAX} - F_3^{GOAL}} \quad \text{if } F_3^{GOAL} \leq \sum_i^8 a_{i3}x_i \leq F_3^{MAX} \end{array} \right\} \\
\lambda_4 &\leq \left\{ \begin{array}{l} \frac{\sum_i^8 a_{i4}x_i - F_4^{MIN}}{F_4^{GOAL} - F_4^{MIN}} \quad \text{if } F_4^{MIN} \leq \sum_i^8 a_{i4}x_i \leq F_4^{GOAL} \\ \frac{F_4^{MAX} - \sum_i^8 a_{i4}x_i}{F_4^{MAX} - F_4^{GOAL}} \quad \text{if } F_4^{GOAL} \leq \sum_i^8 a_{i4}x_i \leq F_4^{MAX} \end{array} \right\}
\end{aligned} \tag{6}$$

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

## 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:

$$\mu_{[F_i(x)]} = \begin{cases} \left[ \frac{F_i(x) - (1-tol) * F_i^{GOAL}}{F_i^{GOAL} - (1-tol) * F_i^{GOAL}} \right], & \text{if } (1-tol) * F_i^{GOAL} \leq F_i(x) \leq F_i^{GOAL} \\ \left[ \frac{(1+tol) * F_i^{GOAL} - F_i(x)}{(1+tol) * F_i^{GOAL} - F_i^{GOAL}} \right], & \text{if } F_i^{GOAL} \leq F_i(x) \leq (1+tol) * F_i^{GOAL} \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

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  $\lambda$

Subject to:

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

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

$$\lambda \leq (0.00479x_1 + 0.05912x_2 + 0.02502x_3 + 0.1874x_4 + 0.01614x_5 + 0.00739x_6 + 0.14510x_7 + 0.00872x_8 - 200886) / (286980 - 200886)$$

$$\lambda \leq (373074 - (0.00479x_1 + 0.05912x_2 + 0.02502x_3 + 0.1874x_4 + 0.01614x_5 + 0.00739x_6 + 0.14510x_7 + 0.00872x_8)) / (373074 - 286980)$$

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

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

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

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

$$x_1 \geq 230000;$$

$$x_2 \geq 66000;$$

$$x_3 \geq 611000;$$

$$x_4 \geq 1338000;$$

$$x_5 \geq 1247000;$$

$$x_6 \geq 210000;$$

$$x_7 \geq 72000;$$

$$x_8 \geq 720000;$$

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

Table 4: Results of the FGP model with tolerance =0.3

Variable	Value	Variable	Value	Variable	Value	Variable	Value
$\lambda_1$	5.61E-08	G1	2724850	$x_1$	230000	$x_5$	3516587
$\lambda_2$	3.52E-06	G2	286980	$x_2$	136704	$x_6$	210000
$\lambda_3$	0.6371894	G3	284739	$x_3$	611000	$x_7$	72000
$\lambda_4$	1	G4	9452000	$x_4$	1338000	$x_8$	3337709

As we see in Table 4, the value of  $\lambda_1$  and  $\lambda_2$  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.

### **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  $\lambda_1$ . 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.

### **Electricity Consumption**

The low value of  $\lambda_2$  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.

### **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<sub>2</sub> capture and sequestration efforts can drastically reduce the CO<sub>2</sub> 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  $\lambda_3$  is reasonably high, but still not unity).

### **Number of Employees**

The value of  $\lambda_4$  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 fuzzy goal programming 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.

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