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Optimal work force allocation for energy, economic and environmental sustainability in the United Arab Emirates: A goal programming approach

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Abstract

Sustainable development is an important and strategic priority for global nations which requires simultaneously satisfying multiple conflicting objectives involving social, economic, energy, and environmental constraints. Multi-criteria decision analysis using a goal programming approach, is a popular and widely used technique to study real world problems involving conflicting objectives due to modelling simplicity and elegance. In this paper we propose a goal programming model that integrates efficient allocation of labour resources to achieve sustainability objectives relating to economic, energy and environmental goals of the United Arab Emirates by the year 2030. The proposed solution provides mathematical and economic justification with critical insights to prioritize areas for strategic planning and resource allocation to develop and implement amenable strategies for sustainability.

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1. Introduction

An agenda for sustainability requires focused efforts to minimize consumption of natural resources, an increased dependence on renewable energy, sustained efforts to reduce GHG emissions and committed leadership. The interaction between energy consumption, economic growth and its effects on

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environmental degradation requires suitable trade-offs to develop amenable policies. The changing demographics and economic growth are contributors to a steep increase in Green House Gas (GHG) emissions and consumption of natural resources. Despite international efforts to reduce emissions, GHG emissions are growing and accumulating at an accelerating pace due to extensive use of fossil fuel based energy sources [1]. To address the sustainability challenge multiple conflicting objectives on economic development, energy consumption, population, social and environment should be simultaneously considered. The objective of this paper is to address some of the criteria towards achieving sustainability goals of the United Arab Emirates (UAE) by the year 2030.

In recent decades the UAE has witnessed remarkable economic growth making it the 7th largest GDP per capita, and the 10th largest oil producing country in the world. The UAE has historically depended on hydrocarbon based revenue since independence in 1971 [2]. To support the rapidly growing economy, increased population and energy needs, the UAE has taken several important initiatives towards economic diversification. In recent years it has heavily invested in non-oil sectors such as technology, infrastructure, education, finance, trade, and manufacturing, to help support long-term sustainability, which provides immunity against oil price fluctuations. Terdiman [3] presents a discussion on the green economy and sustainable development initiatives of the UAE. The UAE Vision 2021 [4] specifically addresses the strong need to develop and promote renewable energy sources advocating lower GHG emissions.

The electricity demand in the UAE has grown from 38600 GWh in 2000 to 79500 GWh in 2009, to 90600 GWh in 2010, with an average annual increase rate of about 8.8% during the last decade [5]. Between the years 2006 and 2011, the annual increase in electricity demand (10.8%) has closely followed the trend in annual population growth of 11% during the same period [5]. The population growth of the UAE has been phenomenal-from 1 million in 1980, to 8.4 million in 2010 and 9.346 million in 2013 [6]. The UAE population constitutes a diverse mix of nationalities and cultures with over 80% expats or non - UAE nationals, with a market heavily dependent on foreign labor for future development and growth. More generally, when comparing the average annual percent change in population, the UAE is placed at 10th among 230 countries with a growth rate of 3.06% [7]. A population growth of this proportion can be directly linked to an increased electricity consumption and over consumption of other natural resources. Conservative estimates predict that the per capita electricity consumption in the Gulf Cooperation Countries (GCC) countries is likely to increase at an annual rate of 2.5% [8]. Electricity generation in the UAE is mainly through natural gas; this leads to severe environmental concerns, including increased production of CO_2, SO_2, and other GHG's and particulate matter. Over 97.5% of power generation across the country comes from natural gas-powered plants [12]. Due to the limited ground water potential, water requirements for the growing population are predominantly met by desalination. Water desalination plants are a significant source of energy consumption, GHG emissions and air pollution [9]. The UAE's CO_2 emissions have increased from 6080 Gg in 1990 to 14690 Gg in 2008 [10]. Of these emissions, the largest contributions were due to power generation [10]. It is interesting to note that the, Middle East and North Africa (MENA) region is regarded as the second most polluted region in the world (following South Asia), which produces the highest CO_2 levels per dollar of output [11]. Population growth and energy consumption are obvious contributing factors to GHG emissions. In 2000, the UAE's total GHG emissions were 128300 Gg of CO_2 equivalent, and the current figures show a 64% increase in total GHG emissions since 1994. In order to meet the long-term emission reduction goals, the top priority is to reduce the need for fossil fuels by investing in clean technologies for energy production. Usage of renewables would present multiple benefits to the UAE, most importantly to reduce the dependence on hydrocarbons.

In this paper we present a goal programming (GP) approach to study the interactions between goals related to electricity consumption (G1), GHG emissions (G2), GDP growth (G3), and number of employees (G4) from various economic sectors and their contribution to the future economic sustainability goals by the year 2030. GP models provide an ideal framework that a decision maker can use to prioritize resource allocation in the presence of multiple competing objectives. GP models are 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 in the decision procedure. A goal is a numerical level (the target level) the DM desires to achieve, relative to each criterion. The numerical limit can be over-achieved, under-achieved or completely achieved.

The paper is organized as follows, In the next section we discuss data preparation and analysis. Section 3 describes the goal programming model and solution, in section 4 we present brief conclusions and future extensions of the model.

2. Data Preparation and Analysis

In this paper we have employed the following 8 economic sectors: (i) agriculture, (ii) crude oil, natural gas and mining, (iii) manufacturing and electricity, (iv) construction and real estate, (v) trade and transport, (vi) restaurant and hotel, (vii) banking and financial corporations and (viii) government, social and personal services.

Sectorial data for various economic, environmental, labour indicators for the UAE were obtained from multiple data sources. The GDP contribution and number of employees was obtained from the Ministry of Economy's Annual Economic Report, 2012[13]. The sectorial data for electricity consumption was obtained from the International Energy Agency with reference to the year 2011[14]. The data obtained did not provide sector specific estimates for electricity consumption; we used the percentile contribution of GDP relative to each sector for disaggregation. GHG emission data for the year 2005 (the most updated entry) was obtained from the Third National Communication under the United Nations Framework Convention on Climate Change, 2013[15]. Table 1 summarizes the per capita contribution of each decision variable used in the model.

Table 1: Sectorial Indicators for United Arab Emirates Economy

Decision Variable	Sector	GDP Per Capita (In Million AED)	Electricity Consumption Per Capita (GWh)	GHG Emissions Per Capita (Gg of CO_2)
X_1	Agriculture	0.03521739	0.00478696	0.01728696
X_2	Crude Oil, Natural Gas & Mining	4.69696970	0.05912121	1.71707576
X_3	Manufacturing & Electricity	0.18134206	0.02502291	0.06629133
X_4	Construction & Real estate	0.08385650	0.01873543	0.00267227
X_5	Trade & Transport	0.17690457	0.01614274	0.00627506
X_6	Restaurant & Hotel	0.08095238	0.00738571	0.00258095
X_7	Banking & Financial Corporation	1.05138889	0.14509722	0.03349306
X_8	Government, Social & Personal services	0.09569444	0.00872083	0.00305000

Table 2 presents the projected goal values for year 2030 with the corresponding growth rates for the four criteria used in the model. The projected population growth in the UAE is estimated to be 12.33 million by the year 2030 [6].

Table 2: Projected values for the identified goals for 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%

3. Goal Programming Model

The GP model is a well-known aggregating methodology for solving multi-objective problems and decision-making processes. GP models simultaneously take into account several conflicting objectives. The solution obtained through the GP model represents the best compromise that can be made by the DM. The first formulation of the GP model was presented in 1955 by Charnes et al. [16], further expanded in Charnes and Cooper [17, 18], Lee [19] and Lee and Clayton [20]. GP models are widely applied in several fields such as: accounting and financial aspect of stock management, marketing, quality control, human resources, production and operations management [22-27]. According to Aouni and Kettani [21] the GP is supported by a well-established network of researchers and practitioners. If $f(x)$ is the vector of criteria to be optimized, g_i is the vector of the goals and D is the feasible set, the standard mathematical formulation of the GP model is as follows:

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

Where δ_i^-, δ_i^+ are, respectively, the negative and the positive deviations with respect to the aspiration levels (goals) g_i, *i=1…p*. An alternative definition of the GP model which will be useful in the sequel is the Weighted Goal Programming (WGP) that can formulated as follows:

$$\begin{aligned} &\text{Min } Z = \sum_{i=1}^{p} w_i^+ \delta_i^+ + w_i^- \delta_i^- \\ &\text{Subject to} \qquad\qquad (2) \\ &f_i(x) + \delta_i^- - \delta_i^+ = g_i, \quad i = 1 \ldots p; \\ &x \in D; \\ &\delta_i^-, \delta_i^+ \geq 0, \quad i = 1 \ldots p \end{aligned}$$

where w_i^-, w_i^+ are the weights associated with the negative and the positive deviations.

3.1. Model Formulation

Using the data presented in Table 1, and the goals for the four criteria set at g_1=2724850, g_2=286980, g_3=284739, and g_4=9452000. The WGP model described in equation (2) with weights w_i equal to 0.25 can be formulated.

The GP model involves the following criteria:

- **Gross Domestic Product**
  $f_1(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) := 0.03521739*X_1+4.69696970*X_2+0.18134206*X_3+0.08385650*X_4+0.17690457*X_5+0.08095238*X_6+1.05138889*X_7+0.09569444*X_8$
- **Electricity consumption**
  $f_2(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) :=0.00479*X_1+0.05912*X_2+0.02502*X_3+0.1874*X_4+0.01614*X_5+0.00739*X_6+0.14510*X_7+0.00872*X_8$
- **GHG emission**
  $f_3(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) :=0.01728696*X_1+1.71707576*X_2+0.06629133*X_3+0.00267227*X_4+0.00563352*X_5+0.00258095*X_6+0.03349306*X_7+0.00305000*X_8$
- **Total work force**
  $f_4(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) := X_1+X_2+X_3+X_4+X_5+X_6+X_7+X_8$

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

Subject to:

$$0.03521739*X_1+4.69696970*X_2+0.18134206*X_3+0.08385650*X_4+0.17690457*X_5+0.08095238*X_6+1.05138889*X_7+0.09569444*X_8+D_{11}-D_{12}=2724850, \quad \text{(i)}$$

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

$$0.01728696*X_1+1.71707576*X_2+0.06629133*X_3+0.00267227*X_4+0.00563352*X_5+0.00258095*X_6+0.03349306*X_7+0.00305*X_8+D_{31}-D_{32}=284739, \quad \text{(iii)}$$

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

$$X_1 \geq 230000, \quad \text{(v)}$$

$$X_2 \geq 66000, \quad \text{(vi)}$$

$$X_3 \geq 611000, \quad \text{(vii)}$$

$$X_4 \geq 1338000, \quad \text{(viii)}$$

$$X_5 \geq 1247000, \quad \text{(ix)}$$

$$X_6 \geq 210000, \quad \text{(x)}$$

$$X_7 \geq 72000, \quad \text{(xi)}$$

$$X_8 \geq 720000, \quad \text{(xii)}$$

$X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8$ are integer (xiii)

$$D_{ij} \geq 0 \quad \text{(xiv)}$$

Some comments on the above formulation

- The objective function includes the weighted summations of all positive and negative deviations of each criterion with respect to its corresponding goal.
- Constraints (i) to (iv) 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 goals.
- The remaining constraints, (v) to (xii) impose that the optimal solution has to preserve at least the current number of jobs, which is a realistic assumption.

3.2. Solution

The solution of the model obtained using LINGO is presented in Table 3. The output shows the presence of a big nonzero deviation in D_{22}. This can be interpreted as follows, to simultaneously satisfy all the four criteria in the model requires a huge amount of energy demand which cannot be satisfied using non-renewable sources. An increase use of hydrocarbon based fuel to satisfy the energy demand, in fact, would increment GHG emissions and this, as a consequence, will affect the values of other deviations involved in the GP model. Therefore to achieve sustainability goals and avoid any increment in GHG emissions, the only reasonable alternative is to alter the energy mix portfolio with alternative energy sources including nuclear, solar and wind to satisfy the growing energy needs.

Table 3: LINGO output of the optimal solution

Deviations	Value	Reduced Cost	Variable	Value	Reduced Cost
D_{11}	0.000000	0.2500000	X_1	230000.0	0.2556801
D_{12}	0.5744599E-01	0.000000	X_2	100323.0	1.009753
D_{21}	0.000000	0.5000000	X_3	611000.0	0.2850177
D_{22}	217404.2	0.000000	X_4	1338000.	0.3171461
D_{31}	0.1457791	0.000000	X_5	5290937.	0.2968528
D_{32}	0.000000	0.5000000	X_6	210000.0	0.2714404
D_{41}	0.000000	0.5000000	X_7	951736.0	0.5407490
D_{42}	0.000000	0.000000	X_8	720004.0	0.2753411

4. Conclusions

Analytical models considering multiple conflicting objectives involving energy, environment and sustainability play an important role in policy planning and development. In this paper we developed a WGP model that integrates optimal work force allocation to simultaneously satisfy the prospective targets of economic development, energy consumption, GHG emission reduction and preserve the job growth by the year 2030 for the UAE. The model offers a mathematical justification for necessary changes to the current energy portfolio, and the importance of using clean energy sources to satisfy the consumption patterns. In the next ten years, the UAE will see the introduction of nuclear power plants and the highly anticipated move towards renewable technologies, namely solar power and wind that holds huge potential for achieving sustainability related goals. The model can be expanded to include stochastic components where the goals, achievement functions and coefficients may not be known with certainty.

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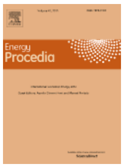

Biography

Raja Jayaraman is an Assistant Professor of Industrial & Systems Engineering at Khalifa University, UAE. He received his Ph.D. in Industrial Engineering from Texas Tech University, USA, a Master of Science in Industrial Engineering from New Mexico State University, USA, Masters and Bachelor degree in Mathematics from India. His research interests includes applied operations research and optimization methods applied to quality control, supply chains, healthcare and environmental sustainability.