A Polynomial Goal Programming Model with Application to Energy Consumption and Emissions in United Arab Emirates

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***Abstract*— Sustainable growth and development of nations requires strategic vision and plan to accommodate growing energy needs while preserving and protecting the natural environment. Studies that couple energy and environment often present conflicting objectives which requires the explicit use of quantitative models to develop appropriate solutions for policy planning and analysis. Goal programming offers an analytical framework to solve multi-objective problems that simultaneously satisfy decision maker's preferences. In this paper we develop a polynomial goal programming model to study the effects of electricity consumption and greenhouse gas emissions applied to the economy of United Arab Emirates. The results provide valuable insights for improvement opportunities and quantitative justification for the required investments and efforts in implementing sustainable development plans.**

Keywords— Polynomial Goal Programming, Sustainable Development, GHG Emissions, Energy Policy

I. Introduction

Sustainability is one of the most difficult challenges affecting the future growth and prospects of global nations. The current rate of population growth combined with the increased energy needs and related environmental issues requires leadership role and a strong commitment to sustainability. The United Arab Emirates (UAE) has high economic and population growth rates and a fairly low energy cost. The energy consumption in the country has risen significantly in the recent decades. This in turn has resulted in a considerable increase in environmental pollution and greenhouse gas emissions (GHG), that have reached a record high, despite the efforts by the government in educating the public about energy conservation and putting numerous environmental policies and regulations in place, and mandating various sectors to abide-by. Currently oil and natural gas are the two main sources of energy production in the UAE with other sources including renewables contributing less than 0.1% [1]. The per capita average annual energy consumption over the years 1990-2011 was 10914.94 kg of oil equivalent [2]. Situated in one of the hottest regions in the world, a large portion of energy is expended for temperature control in residences and workplaces. In addition, the ongoing construction mega-projects are major sources of energy demand. Electricity demand has always been anticipated to increase as a global trend. It is particularly expected to rise in the coming few years in the UAE, thanks to its tremendous socio-economic development witnessed in recent times expected future projections. Particularly in the GCC countries, the future electricity demand is anticipated to be 80% higher than the currently installed capacity in the near future [3].

The UAE is the world's 10th largest per capita electricity consumer [1]. The electricity demand was 38.6 TWh in 2000, which rose to 79.5 TWh in 2009 and to 90.6 TWh in 2010 [4]. Between the years 2006 and 2011 alone, the electricity demand grew by 10.8% annually, in proportion with the annual population growth of 11% in the same years [1]. Electricity generation in the UAE stood at 25 BkWh in 1996 that grew to 57.1 BkWh in 2005 [3] to 91.52 BkWh in 2011 (U.S. Energy Information Administration, [35]). Figure 1 presents the net electricity consumption in UAE for the years 1980-2011. Oil production in the UAE has been compliant with the international oil market, whereas the demand has been on a consistent increase. UAE together with the other ten member nations of OPEC contribute about 40% of the world's oil output, and the OPEC countries possess more than three-quarters of the world's proven crude oil reserves [3]. At the same time, in 2011, nearly 0.1% of the world's population residing in the UAE consumed 0.8% of the oil produced worldwide [1]. It has been observed that the oil and gas share in the energy mix has not changed considerably for the local production over the years 2001-2011, whereas the overall energy consumption has multiplied by 1.66, or a 5.2% annual increase [1]. UAE has world's 7th largest gas reserves (2.9% of the world's proven reserves), yet since 2007, it has become a natural gas importer, owing to the high energy consumption and a gradual shift towards gas-based power generation capacity. Over 45% of gas consumed locally is used for power production [1]. The growing energy demand with the current and anticipated gas shortages are clear drivers of the motivation to generate electricity from a diversified energy mix, including coal, nuclear energy, and renewable energy sources.

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Fossil fuel sources contribute largely to the CO_2 and other GHG emissions, hence adversely impacting the environment. Air quality is one of the top environmental concerns in the UAE, where over 500 deaths per year are attributable to ambient air pollution [5]. Kyoto protocol classifies the UAE as a Non-Annex 1 country. This means the country is permitted to further emit CO_2 and do not have to adhere to legally binding emission reduction targets. In 2005 however, the UAE was one of the first major oil producing countries to commit to the protocol by establishing one of the worlds's most comprehensive clean energy initiatives [6]. The UAE's CO_2 emissions increased from 60.8 Mt in 1990 to around 94.2 Mt in 2002 [4,6], which scaled up to 146.9 Mt in 2008 [6]. Average annual CO_2 emissions were measured at 27,262 Mt per capita over the 1990-2011 period [2]. In 2005, UAE's share in CO_2 GHG emission among the GCC countries was 18.75%, at 137.82 Mt compared to 103Mt in 1996 [3]. Over 65% CO_2 emissions are attributable to the power sector, which shows a clear need for a shift in reliance from fossil fuels to alternative energy sources such as nuclear power and renewable technologies [6]. The UAE's technical potential of solar energy is about 2078TWh [4] and the abundant solar exposure is a factor for solar energy dominance on non-fossil fuel energy sources [1]. The current gross domestic product of UAE is $383.2 billion and is projected to grow between 4-6% until 2030 [7]. The UAE Vision 2021 [8] lays a strong foundation to address the sustainability issues relating to diversification of energy resources, lowering carbon emissions towards achieving a balanced economic growth.

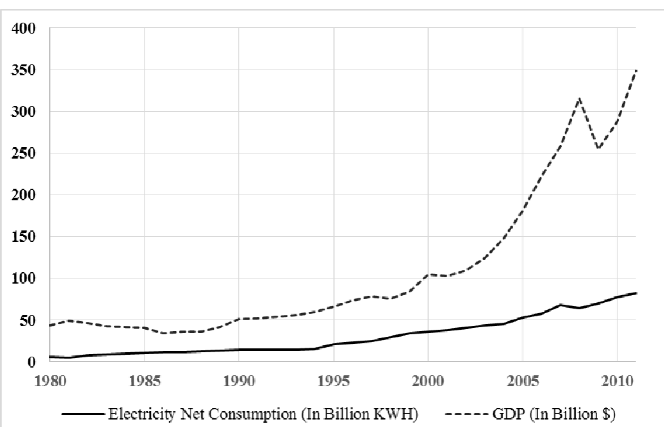

Figure 1: Net electricity consumption and GDP growth in the UAE between 1980-2011. Source: US Energy Information Association and World Bank.

In this paper we develop a Polynomial Goal Programming (PGP) model to study the effects of electricity consumption and GHG emissions on various economic sectors of the UAE towards achieving important developmental goals by the year 2030. The conclusions derived from the model provide directional insights to policy planning and public economics to channelize efforts on areas of potential development. The conclusions presented in this work also provide a quantitative basis for future investments in sustainable development.

The rest of the paper is organized as follows; in section II we present a review of literature on goal programming models to study energy and environmental effects. In Section III we discuss data collection and assumptions used in this work. Section IV describes the goal programming model and the obtained solutions. Finally in Section V we discuss conclusions based on the model

II. RELATED LITERATURE

Goal Programming (GP) models have been extensively used to study energy and environmental planning problems. The objective of GP model is to obtain amenable solution to conflicting goals while minimizing the deviation of the optimal solution from the objectives [9,10,11]. The simplicity of GP models makes it more attractive and applicable for modeling variety of multi-criteria problems applied to energy and environment. We refer the readers several historic papers by Charnes and Cooper [12-15] and Lee [16], Lee and Clayton [17] and a recent survey on GP models in portfolio optimization [37].

The PGP model has been extensively used in portfolio management and finance. Lai (1991) proposed the first PGP model to determine the mean-variance-skewness portfolio frontier; in his model he incorporated the Financial Decision Maker's (FDM) preferences regarding the skewness as follows:

$$\text{Minimize } Z = d_1^{p_1} + d_2^{p_2}$$

Subject to:

$$\sum_{j=1}^{n} x_j E_j + d_1 = E^*,$$
$$\sum_{j=1}^{n} x_j \left(r_j - E_j\right)^3 + d_2 = S^*,$$
$$\sum_{j=1}^{n} \sum_{k=1}^{n} x_j x_k \sigma_{jk} = 1,$$
$$\sum_j x_j = 1,$$
$$x \in F,$$
$$d_1 \text{ and } d_2 \geq 0.$$

Where p_1 and p_2 are preference parameters which describe various combinations of portfolio compositions. The first and the second constraints describe the difference between the achievement level and the corresponding goals for both the expected return and the skewness criterion. According to [18], the PGP model integrates the FDM's preferences regarding the skewness objective and is more efficient than the classical GP model: indeed the PGP model presents the flexibility of incorporating the higher moments of the probability distribution. [19] and [20] have applied [18] PGP model by considering the investor preferences for positive skewness. They discussed various degrees of investor trade-off between the importance of skewness and return. A more recent PGP model is developed by Sun and Yan [21] who examine individual equities in the Japanese and US markets. All the above mentioned papers show the importance of explicitly considering higher moments. Lai *et al.* [22] extend the Lai

[18] model by analyzing a mean-variance-skewness-kurtosis-based portfolio model. Canela and Collazo [23] have revised the different PGP formulations proposed by Lai [18], Chunhachinda et al. [19], Prakash et al. [20] and Sun and Yan [21] based on the fact that these formulations may lead to unfeasible solutions. In their paper and PGP model, Lucey et al. [24] show the changes in portfolio composition when considering skewness and the role of gold. Finally Davies et al. [25] reveal the importance of equity market neutral funds as volatility and kurtosis reducers, and of global macro funds as portfolio skewness enhancers.

Ballarin et al., [26] developed a multi-period Weighted Goal Programming (WGP) model to analyze the issues related to net energy production from biomasses applied to Italy. They identified the optimal land use combinations that simultaneously maximize farmers' income and the net biomass energy production. The tradeoff between the maximization of the farmers' net income and the net energy production was highlighted. Borger and Antunes [27] developed a fuzzy goal programming approach to model energy-economy planning applied to Portugal. Pal and Kumar [28] use the revised multi-choice goal programming approach for modeling and solving economic-environmental power generation and dispatch problems in a thermal power plant operation. Chang [29] proposes a multi objective goal programming approach to identify the key CO_2 emission sectors and the optimized production structure with respect to the goal of emission reduction. The proposed approach was applied to 2007 data from China. San Cristobal [30] developed a goal programming model based on an environmental input–output linear programming model applied to the Spanish economy. Their model discussed the effects on output and labor across different sectors in reducing the emission levels and energy requirements.

III. Data collection

In this paper we have used the following decision variables to represent key economic sectors in 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). Sectorial data for various indicators such as economic productivity, energy output, electricity consumption, labor and employment indicators were not readily available. The GDP contribution and number of employees in each sectors were obtained from the UAE Ministry of Economy's Annual Economic Report, 2012[31]. The population demographics in the UAE represent a diverse mix of nationalities and the UAE citizens. In 2013, the total population in the UAE was approximately 9.2 million [32], of which approximately 7.8 million were expatriates. To sustain the high economic growth and standard of living UAE is heavily reliant on expatriate labor force [33].

The sector data for electricity consumption were obtained from International Energy Agency with reference to year 2011[34]. The presented data did not provide sector specific estimates for energy consumption; we used the percentile contribution of GDP relative to each sector for disaggregation. Electricity consumption data presented in four categories, (a) residential, (b) industrial, (c) commercial and public services, (d) others non-specified categories were disaggregated to provide estimates of consumption for the eight decision variables used in the PGP.

GHG emission data for year 2005 (the most updated entry) were obtained from 3rd National Communication under the United Nations Framework Convention on Climate Change (UNFCC), [36]. The total GHG emissions 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 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. This model did not take into account of carbon capture and sequestration efforts.

TABLE I. Per capita estimates of key economic sectors

Decision Variable	Sector	Per capita Electricity Consumptio n (In Gwh, Year 2011)	Per capita GHG Emissions (In Gg Co2 Equivalent, Year 2005)
X_1	Agriculture	0.004786957	0.0172869
X_2	Crude Oil, Natural Gas & Quarrying	0.059121212	1.7170757
X_3	Manufacturing & Electricity	0.025022913	0.0662913
X_4	Construction & Real Estate	0.018735426	0.0026722
X_5	Trade& Transport	0.016142743	0.0062750
X_6	Restaurant & Hotels	0.007385714	0.0025809
X_7	Banking &Financial Corporations	0.145097222	0.0334930
X_8	Government, Social & Personal Services	0.008720833	0.00305

Table I provides the per capita estimates of the contribution made by each sector relative to eelectricity consumption and GHG emission. Goals for the model were projected with the following assumptions, data related to GDP growth were projected at 7% to reach 2,725 billion AED by the year 2030, electricity consumption was projected to reach 286,980 GWh in 2030 at 8% growth, GHG emissions projected to reach 284,739 Gg of CO_2 equivalent at 2% growth. The projected population growth in the UAE by 2030 is estimated to be 12.33 million in 2030 (UN World Population Prospects[32]).

IV. GOAL PROGRAMMING MODEL

In the following we consider the following PGP model which allows to determine the optimal allocation of labor resources across different sectors to sustain the GDP growth subjected to achieving the goals relating to electricity consumption and GHG emissions. The following two criteria f_1, f_2 will be used in the sequel:

1. Electricity consumption:

$f_1(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8):=$
$0.00479*X_1+0.05912*X_2+0.02502*X_3+0.1874*X_4+$
$0.01614*X_5+0.00739*X_6+0.14510*X_7+0.00872*X_8$

2. GHG emissions:

$f_2(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) :=$
$0.01728696*X_1+1.71707576*X_2+0.06629133*X_3+$
$0.00267227*X_4+0.00627506*X_5+0.00258095*X_6+$
$0.03349306*X_7+0.00305000*X_8$

The Polynomial Goal Programming model we are interested in can be formulated as follows:

Minimize $D_1^2 + D_2^2$;

Subject to:

$0.00479*X_1+0.05912*X_2+0.02502*X_3+0.1874*X_4+$
$0.01614*X_5+0.00739*X_6+0.14510*X_7+0.00872*X_8-$
$D_1=286980$;

$0.01728696*X_1+1.71707576*X_2+0.06629133*X_3+0.$
$00267227*X_4+0.00627506*X_5+0.00258095*X_6+0.03$
$349306*X_7+0.00305000*X_8-D_2=284739$;

$X_1+X_2+X_3+X_4+X_5+X_6+X_7+X_8\leq 9452000$;

$0.03521739*X_1+4.69696970*X_2+0.18134206*X_3+0$
$.08385650*X_4+0.17690457*X_5+0.08095238*X_6+1.$
$05138889*X_7+0.09569444*X_8\geq 2724850$;

$X_1\geq 230000$;
$X_2\geq 66000$;
$X_3\geq 611000$;
$X_4\geq 1338000$;
$X_5\geq 1247000$;
$X_6\geq 210000$;
$X_7\geq 72000$;
$X_8\geq 720000$;
$D_1\geq 0$;
$D_2\geq 0$;
$X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8$ are integers

Where:

- D_1 and D_2 represent deviations from goals relating to energy consumption and GHG emissions
- The objective function takes into account the squared summations of deviation of each criterion with respect to its corresponding goal.
- The first two constraints 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 impose that the total population cannot be above a certain level, that the GDP cannot be under a certain threshold, and that the optimal solution has to preserve the current number of jobs.

LINGO was used to obtain the following optimal solution

Table II.

Global Optimal Solution	
Objective value:	0.4133276E+11
Objective bound:	0.4133274E+11
Infeasibilities:	0.000000
Extended solver steps:	14
Total solver iterations:	946
Elapsed runtime seconds:	0.06
Model Class:	MIQP
Total variables:	10
Nonlinear variables:	2
Integer variables:	8
Total constraints:	13
Nonlinear constraints:	1
Total nonzeros:	44
Nonlinear nonzeros:	2

Table III.

Variable	Value
D_1	188954.7
D_2	75026.01
X_1	230000.0
X_2	145945.0
X_3	611000.0
X_4	1338000
X_5	5481127
X_6	210000.0
X_7	715924.0
X_8	720000.0

Table III provides significantly large nonzero values for the deviations D_1 and D_2. These information provides some recommendations to policy makers, and can be interpreted as follows: if permitted to emit little bit more GHG (D_2 different than zero), then we can reduce the total demand of energy production. However, as D_1 is non-zero, the only way to compensate the energy consumption level without increasing the pollution levels is to make investments in to diversify the energy portfolio to include alternate and renewable sources of energy.

V. Conclusion

In this paper we presented a polynomial goal programming model to study the effects of electricity consumption and greenhouse gas emissions applied to the economy of United Arab Emirates. UAE Vision 2021 addresses the key issues of sustainability that requires augmenting current energy mix with alternate and renewable sources of energy and a strong push for lowering domestic GHG emissions. The conclusions of the model can be interpreted as the optimal achievable extent of energy production is contingent on certain positive deviation from the objective level of pollution, highlighting the energy-environment antagonism. This optimal energy-production value itself has an associated positive deviation. Thus it is imperative, for attaining the targeted electricity production level without adding further to the pollution, is to diversify the energy portfolio through the inclusion of alternate and renewable energy sources. The UAE is a relatively young nation witnessing rapid economic growth with a strong commitment to meet future challenges, and as regional and international leader has taken leadership role evidenced by establishing world's first renewable energy agency (IRENA), harnessing wind energy and concentrated solar power (Shams 1), MASDAR city to promote urban sustainability, to name a few. The results from the model provides a mathematical validation to satisfy conflicting goals on electricity demand and GHG emissions while achieving GDP growth targets for year 2030. Additionally the results provide a quantitative justification for additional investments in the energy sector to achieve the strategic priorities of year 2030.

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Biography

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Davide La Torre is Associate Chair of the Department of Applied Mathematics and Sciences of Khalifa University, Abu Dhabi, UAE. He has spent several research periods at a number of institutes, including: the Department of Applied Mathematics of the University of Waterloo (Canada), the Department of Mathematics of the Australian National University (Australia), the Department of Mathematics and Statistics of the University of Guelph (Canada), the Department of Mathematics and Statistics of Acadia University (Canada), the School of Commerce and Administration of Laurentian University (Canada), the Department of Applied Mathematics of the University of Granada (Spain), and the Department of Economics and Related Studies of the University of York (UK). Davide La Torre has authored and co-authored 80 research papers on MathSciNet, many of them published in leading international mathematical journals. He has also edited and co-edited special issues for several journals and he is the Editor of the International Journal of Applied Nonlinear Science.

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Yanthe E. Pearson joined the Department of Applied Mathematics and Sciences Department of Khalifa University, Abu Dhabi, UAE. In 2009, she completed her Ph.D. in Mathematics at Rensselaer Polytechnic Institute (USA). Following her studies, she spent one year at New York University School of Medicine as a postdoc in the Department of Theoretical Immunology. In August 2010, Dr. Pearson accepted a two year postdoctoral position at the University of Maryland College Park in the Department of Biology to work on developing theoretical models for applications in comparative phylogenetics. Her research work has been published in a wide range of applied mathematics, statistics and applied science journals.