Applied Energy 104 (2013) 924–935

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Sustainable urban energy planning: The case study of a tropical city

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HIGHLIGHTS

- ▶ Sustainable energy planning of tropical cities with hybrid energy technologies competes on economic and environmentally issues.
- ▶ We examine variations in the level of energy production.
- ▶ The energy planning of cities involves the exportation of pollutants and/or importation of external energy.

ARTICLE INFO

Article history:
Received 3 November 2011
Received in revised form 4 December 2012
Accepted 6 December 2012
Available online 9 January 2013

Keywords:
Energy policy
Optimization modeling
Integrated resources planning
Cities

ABSTRACT

The urbanization of modern societies has imposed to the planners and decision-makers a more precise attention to facts not considered before. Several aspects, such as the energy availability and the deleterious effect of pollution on the populations, must be considered in the policy decisions of cities urbanization. The current paradigm presents centralized power stations supplying a city, and a combination of technologies may compose the energy mix of a country, such as thermal power plants, hydroelectric plants, wind systems and solar-based systems, with their corresponding emission pattern. A goal programming multi-objective optimization model is presented for the electric expansion analysis of a tropical city, and also a case study for the city of Guaratinguetá, Brazil, considering a particular wind and solar radiation patterns established according to actual data and modeled via the time series analysis method. Scenarios are proposed and the results of single environmental objective, single economic objective and goal programming multi-objective modeling are discussed. The consequences of each dispatch decision, which considers pollutant emission exportation to the neighborhood or the need of supplementing electricity by purchasing it from the public electric power grid, are discussed. The results revealed energetic dispatch for the alternatives studied and the optimum environmental and economic solution was obtained.

1. Introduction

Since the 1970s, with the petroleum crisis, energy and environmental questions have become a key concerns for policymakers and societies across the globe. Those questions motivated individual and collective behavior modification on the use of the energy in the next decades. As a consequence, themes such as natural resources use and environmental impacts of energy generation technologies, the use of renewable energy and the disposal solid wastes and/or equipments after their lifetime are under discussion by the society.

The sustainability of cities is a theme with high pertinence in the current world context; the technological, social, economic and environmental aspects of the urbanization process present important intersections. The division of spaces, the evolution of environments, the definition of green areas and sector areas for activities such as commerce, industrial poles, land-filling, among others, are the object of urban analysis [1]; associated with the geo-processing of images and with the help of mathematical optimization, the urban planning can conceive the best plans of streets and avenues, the location of services and public equipments, the definition of bus routes and surface trains [2,3], among others.

From the environmental viewpoint, cities also demand urgent answers, for which mathematical methods of evaluation have been revealed favorable – vehicles emissions, appropriate disposition and elimination of solid wastes [4], meeting of crescent drinking water needs [5] and sewage collection and treatment are some of the points that deserve special attention. It is opportune to mention that the sustainability of public buildings has also been

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http://dx.doi.org/10.1016/j.apenergy.2012.12.022

Nomenclature

AR	autoregressive model's order coefficient
bio	energy generation by biogas, kW h/year
C	reference cost, US$/kW h
Cco	public electric power grid reference CO_2 emission level, kg/kW h
Cl	climatologic values for the points of a grid at a given time
Cno	public electric power grid reference NO_x emission level, kg/kW h
CO	CO_2 emission level for the generating system at the year, kg/kW h
CO_2^+	upper bounds for the CO_2 emission level, kg/kW h
CO_2^-	lower bounds for the CO_2 emission level, kg/kW h
Cso	public electric power grid reference SO_2 emission level, kg/kW h
Ct	time series constant term
D	incremental yearly energy consumption, kW h/year
d^-, d^+	under- and over-achievement of generic objectives
E	yearly generated energy, kW h/year
FC	capacity factor
e^-, e^+	under- and over-achievement of generated energy goal, kW h/year
HPY	time of use, h/year
H	height, m
i	interest rate
I	incremental investment cost for the generating system at the year, US$/year
L	solar panel length, m
LF	load factor for the generating system, %
M	forecasted (modeled) values
MA	moving average models order coefficient
m^-, m^+	under- and over-achievement of economic issue goal, US$/year
n	useful life, year
NO	NO_x emission level for the generating system at the year, kg/kW h
NO_x^+	upper bounds for the NO_x emission level, kg/kW h
NO_x^-	lower bounds for the NO_x emission level, kg/kW h
NP	number of solar panels
P	yearly generated energy for the technology, kW h/year
p^-, p^+	under- and over-achievement of pollutant emissions from energy source goal, kg/kW h
O	observed values
Q	mass flow, kg/s
SO	SO_2 emission level for the generating system at the year, kg/kW h
SO_2^+	upper bounds for the SO_2 emission level, kg/kW h
SO_2^-	lower bounds for the SO_2 emission level, kg/kW h
v^-, v^+	under- and over-achievement of environmental issue goal, kg/year
W	solar panel width, m
X	forecasted value of solar radiation
Z	the residual value

Greek symbols

$\alpha_{k,j}$	specific cost per installed power for the kth technology, jth year, US$/kW
$\beta_{k,j}$	net present value for the kth technology and for the jth year, US$/year
δ	the error coefficient: average error between forecasted and observed values
ε^-, ε^+	weights of under- and over-achievement of considered objectives
λ	photovoltaic factor
η	efficiency

Subscripts

avg	average
f	future year
grid	public electric power grid reference
k	identification of electric generating technology
j	identification of the year under analysis
max	maximum
min	minimum
mod	solar module
pv	photovoltaic
pc	panel conditioning
rce	reciprocating combustion engine
t	time

considered for the reduction of water use (and abuse), as well as the electric and thermal (air conditioning) power consumption reduction opportunities for attending certification patterns, as showed in "Leadership in Energy and Environmental Design" (LEED) program [6,7]. Along with those facts there are social and cultural conditions that involve educational and public health aspects.

In the technical sense, the cities sustainability is associated to several applications; the feasibility analysis of micro-cogeneration applied to condominiums and buildings is becoming more present in the technical literature, revealing to be favorable in some situations [8]; the adoption of rational use of energy and water practices can be associated to thermal storage systems for the production of heating and cooling; the energy produced from solid wastes or sewerage incineration, or even the generation of energy with consequent reduction of methane emissions to the atmosphere in sanitary landfills [9,10] are interesting themes related to technological, economic and environmental techniques.

Regardless its size, a city can be characterized by common structures conceived to accommodate commercial, industrial, domestic and municipal needs. For attending such structure requirements, scenarios and criteria for reaching the balance between energy supply and demands must be provided [11]. An energy policy must be developed favoring the socioeconomic development according to sustainable conditions. It is possible to reorganize society inducing positive actions, such as the reduction of energy and goods consumption, the identification of new uses for old equipment and also the recycling of products.

Renewable energy technologies generally have public easy acceptance, being solar energy advisable for residential and similar use, biomass for industrial and related activities and wind energy for agriculture [12], despite some low societal acceptance in some countries. In the case of the water, the recycling of served water for irrigation and the use of underground water in the industrial and domestic provision is proposed according to the local context. In locations with rigorous winters, the district heating is a recommended practice in the cogeneration context. This alternative is environmentally acceptable because it reduces the fuel burning (and consequently reduces the CO_2 emissions) for the thermal and electric attendance of urban center requirements.

As an example of energy planning of cities, Bruckner et al. [13] developed a dynamic energy optimization model for analyzing competition and synergy between different technologies of rational use of energy and of renewable energy use. The model