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A renewable energies-assisted sustainable development plan for Iran using techno-econo-socio-environmental multivariate analysis and big data

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ABSTRACT

In the present study, sustainable development is investigated in Iran using renewable energies-assisted Techno-Econo-Socio-Environmental Multivariate Analysis (TESEMA) as a novel holistic approach. Accordingly, six annual hourly consumption variables, reported by Iran's power industry from 2011 to 2017, are predicted using seven dynamic and intelligent models. Consequently, technical and economic variables are obtained by an optimal design of hybrid solar, wind, and biogas systems at 53 sites in Iran. Thirteen social variables are studied using a technique for order-preference by similarity to an ideal solution (TOPSIS) and six hazardous air pollutants are reported in Iran using a geographic information systems interpolation tool. Then, four major TESEMA variables are used in multivariate statistical analyses to reduce the big data diversity. Principal component analysis (*PCA*) is performed to find a linear model among the variables, and *K* nearest neighborhood (*KNN*) algorithm is used to cluster the sites according to the modeling results. A partial least square-based regression is conducted to investigate any correlation between major variables of TESEMA and population density in Iran. Finally, TESEMA development index (*DI*) and facial graphs are proposed as novel numerical and graphical sustainable development monitoring techniques, respectively. The results show that *DNN* is the best model to predict demand load in Iran (*RMSE* = 73.15%). Since *DI* varies in a wide range from 0 to 248.83 and the population density is significantly correlated with TESEMA variables (R^2 = 91.86%), the current centralistic policies should be revised in Iran to reach sustainable development. Thus, a four-cluster management strategy accompanied by smart monitoring can efficiently lead to sustainable development in Iran.

1. Introduction

Sustainable development has become a driving paradigm of development in the 21st century. Sustainable development is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs [1]. Energy is an indispensable part of the sustainable development programs of competitive, industrialized, modern nations [2]. However, the precious resource of welfare and development turns to threat the sustainability aspect if only the low cost energy generation is mentioned in a short term policy. Thus, energy efficiency and renewable energy production are twin pillars of a sustainable energy system, and accordingly, much research has focused on these two topics [3].

Lee et al. [4] maximized the sustainability of an integrated wastewater treatment plant and a combined heat and power system using a novel, multi-objective optimization method. The total cost rate and total environmental impact were simultaneously minimized using a multi-objective genetic algorithm. In other research, a conventional steam power plant was promoted to an integrated absorption chiller and power plant in order to decrease water losses in the wet cooling tower. This alteration improved the energy conversion and thus the system's performance and ecological sustainability in an arid region [5]. Two highly efficient cogeneration systems were proposed based on Kalina and absorption refrigeration cycles. The systems were capable of reducing total annual costs by 8% while increasing thermal efficiency by approximately 5% [6]. Studies of this type focus on efficiency improvements in the existing energy systems.

Iran is a challenging case study among energy intensive countries where the energy consumption per capita is 10 times that of the European Union [7]. Thus, numerous research articles tackle the energy consumption problem using novel energy management methods. Royan et al. [8] investigated energy balance of peach production in a province of Iran. The results showed that direct and indirect shares of energy consumption were 50.98% and 49.02%, respectively. The authors

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Nomenclature

$y(t)$	model output at time t
n_a	number of poles
n_b	number of zeros plus 1
$e(t)$	white noise disturbance value
n_c	number of coefficients
n_k	number of input samples
n_j	system delay
Ar	province area
$\mathbf{Y}$	a matrix in the orthogonal coordinate system
$\mathbf{B}$	regression coefficients
$\mathbf{F}$	residuals matrix
x_i	input to node i
v_{ji}	connection weight between i and j
y_k	output from node k
z_j	output from hidden node j
a_j	activation in the jth layer
a_i	activation in the ith layer
w_i	connection weight
b_i	connection bias
y_i	ith observed value
y_i'	ith predicted value
x_{loc}	local demand load
x_{pred}	predicted demand load
P_r	population at an electrical region
P_{des}	design population
rf	regional load factor
$P_{load}(i)$	demand load at time i
P	power
r_{ij}	jth social variable in the ith province
$P_{B,charge,\min}$	minimum battery charge limit
Y_{PV}	PV module power output at STC
f_{PV}	PV derating factor
$G_{T,STC}$	solar radiation incident at STC
G_T	total solar radiation
$T_{C,STC}$	PV cell temperature at STC
T_C	PV cell temperature
T_a	ambient temperature
$T_{C,NOCT}$	nominal operating cell temperature
G_g	global radiation
G_d	diffuse radiation
R_b	average beam on a tilted to a horizontal surface ratio
R_D	average diffuse on a tilted to a horizontal surface ratio
F_{total}	total loss factor
ρ_{hub}	air density at the hub height
Z_0	surface roughness length
V_{anem}	wind speed at anemometer height
$Q_{\max}$	total capacity of the battery bank
c	battery capacity ratio constant
k	battery capacity rate constant
N_B	number of batteries
$I_{\max}$	battery's maximum charge current
V_{nom}	nominal voltage
ir	interest rate
i_{nom}	nominal discount rate
f	inflation rate
lc	project lifetime
N_{ij}	projection value
c_l	cluster centroid
$\mathbf{A}^T$	transpose of an orthogonal matrix
$\mathbf{S}$	random vector
$\mathbf{V}$	weighted normalized decision matrix
cl_i^+	distance ratio
$E(C)$	Euclidean norm

Abbreviations

API	air pollution index
GIS	geographic information system
TESEMA	techno-econo-socio-environmental multivariate analysis
TOPSIS	technique for order-preference by similarity to ideal solution
SV	social variable
SDI	social development index
BSM2	benchmark simulation model No. 2
AD	anaerobic digestion
OPU	optimal power usage
GL	total grid length
GM	grid maturity
EP	excess power
SR	social revenue
EC	environmental cost
AOC	annualized operation cost
ACC	annualized capital cost
TAC	total annual cost
BF	biogas fraction
EP	excess power
WF	wind fraction
SF	solar fraction
Lon.	longitude
Lat.	latitude
Elev.	elevation
ARX	autoregressive exogenous
ARMAX	autoregressive moving average exogenous
OE	output error
BJ	Box–Jenkins
PLS	partial least square
RNN	recurrent neural network
DNN	deep neural network
RMSE	root mean square error
T	temperature
GHR	global horizontal irradiation
IDW	inverse distance weight
PCA	principal component analysis
WS	wind speed
NASA	National Aeronautics and Space Administration
SUNA	Renewable Energies Organization of Iran
IRMO	Iran meteorological Organization
PV	photovoltaic
WT	wind turbines
BG	biogas generator
C	converter
B	battery
DC	direct current
AC	alternating current
HRES	hybrid renewable energies system
LPSP	loss of power supply probability
STC	standard test conditions
kbm	kinetic battery model
mcr	maximum charge rate
mcc	maximum charge current
MNPC	modified net present cost
KNN	K nearest neighborhood
PD	population density
GWP	global warming potential

Greek letters

$\eta_{B,rt}$	battery round trip efficiency
$\eta_{B,charge}$	battery charge efficiency