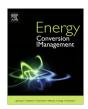
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A systematic approach of bottom-up assessment methodology for an optimal design of hybrid solar/wind energy resources – Case study at middle east region



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ABSTRACT

In the current study, an algorithm-based data processing, sizing, optimization, sensitivity analysis and clustering approach (DaSOSaCa) is proposed as an efficient simultaneous solar/wind assessment methodology. Accordingly, data processing is performed to obtain reliable high quality meteorological data among various datasets, which are used for hybrid photovoltaic/wind turbine/storage/converter system optimal design for consequent sites in a large region. The optimal hybrid systems are consequently simulated to meet hourly power demand in various sites. The solar/wind fraction and net present cost of the systems are then used as the technical and economic clustering variables, respectively. The clustering results are finally used as input to obtain novel hybrid solar/wind GIS maps. Iran is selected as the case study to validate the proposed methodology and detail its applicability. Ten minute annual global horizontal radiation, wind speed, and temperature data are analyzed, and the optimal, robust hybrid systems are simulated for various sites in order to classify the country. The generated GIS maps show that Iran can be efficiently clustered into four technical and five economic clusters under optimal conditions. The clustering results prove that Iran is mainly a solar country with approximately 74% solar power fraction under optimum conditions. A macroeconomic evaluation using DaSOSaCa also reveals that the nominal discount rate is recommended to be greater than 20% considering the current economic situation for the renewable energy sector in Iran. An environmental analysis results show that an average 106.68 tonCO₂eq/year is produced for such hybrid systems application in Iran during a cradle to grave life cycle. Thus, Iran energy sector can be eminently promoted to an environmentally efficient stage with regard to the proposed classification plan and economic considerations.

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1. Introduction

An increase in energy demand, the depletion of conventional fossil fuel resources, and the deterioration of environmental conditions have seriously called into question traditional global energy trends. Therefore, many developing and developed countries have concluded that elaborate investment in renewable energies is a promising approach to reach sustainable growth, so that approximately 18% of the total global energy demand is currently being met by green energies [1].

Following the global trend, the European Union, the wealthiest economic body in the world, has committed to producing 27% of its

electricity using renewable energy sources by the year 2030 in order to reduce its fast growing energy imports [2]. The United States aims to increase the renewable share of its energy sector from the current 9% to 12% of total domestic consumption by 2020 [3]. Bringing CO₂ emissions under control has motivated developing countries to invest in alternative energies. China, which is the fastest developing country, set a goal of having an approximately 20% share of non-fossil fuels by 2030 [4]. It is also anticipated that Middle Eastern countries, the heart of the world's fossil fuel reserves, will increase renewable sources utilization by 16% until 2035 [5]. Iran, as an instance, has planned to meet 2 GW of its energy-intense market requirements using renewable energies [6].

The above-mentioned long-term ambitious energy goals will be achieved if and only if accurate plans are set. As a first step, the

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Nomenclature time interval rate constant scenario indicator battery's maximum charge current I_{max} $P_{B,ch\,arg\,e,min}$ the minimum battery charge limit K_T clearness index minimum temperature nominal discount rate T_{\min} acceptable temperature project lifetime T_{acc} 1c maximum temperature distance between a pair of items T_{max} minimum wind speed number of items in cluster Z WS_{\min} N_7 WS_{acc} acceptable wind speed total wind power $P_{WT.farm}$ maximum wind speed total loss factor WS_{max} F_{total} cluster centroid F_{array} array loss factor c_k number of data points wind turbine contingency losses n_k F_{other} global gas constant *i*th data point in the cluster *k* wind power density P_{hub} E(C)sum of Euclidean norms swept area by the turbine rotor available data x_i d_i difference between a pair of data **Abbreviations** S_d S_d^2 data standard deviation renewable energy data variance PV photovoltaic P_{load} design population demand load WT wind turbine P_{peak} N_B population peak demand load K nearest neighborhood KNN battery bank size loss of power supply probability LPSP converter size N_C kbm kinetic battery model photovoltaic bank size N_{PV} тсс maximum charge current N_{WT} wind turbine size NPC net present cost f_{PV} PV derating factor TAC total annual cost solar radiation incident in standard test conditions $G_{T,STC}$ interest rate ir total solar radiation G_T ACC annualized capital cost PV cell temperature under standard test conditions $T_{C,STC}$ WF wind fraction PV cell temperature T_C GIS geographic information systems ambient temperature T_a maximum charge rate mcr nominal operating cell temperature $T_{C.NOCT}$ ACF one hour autocorrelation factor solar radiation of NOCT $G_{T,NOCT}$ SF solar fraction G_B direct solar beam CRF capital recovery factor diffuse irradiance G_D AOC annualized operating cost grand reflected irradiance G_R **IDW** inverse distance weight global radiation on a horizontal surface G_g LF load factor diffuse radiation on a horizontal surface G_d DPS diurnal pattern strength R_b average beam ratio **HPWS** hour of peak wind speed extraterrestrial daily radiation G_o **GWP** global warming potential day of a year given for each month greenhouse gas GHG theoretical wind power Ptheory C_P maximum theoretical efficiency Greek letters downtime loss factor $F_{downtime}$ type I error probability icing/soiling loss factor F_{icing} satellite-based data mean gauge wind turbines practical power mu_{sat} $P_{WT,gauge}$ ground-based data mean total capacity of the battery bank Q μ_{site} temperature coefficient of power battery capacity ratio Cmaximum power point efficiency under standard test time step length Δt $\eta_{mp,STC}$ V_{nom} conditions nominal voltage solar transmittance $P_{load}(i)$ demand load at a time interval i τ PV array solar absorptance inflation rate latitude $P_{PV,module}$ total PV module power φ solar declination wind speed at time interval i U_i Weibull shape factor hour angle wss ground albedo Weibull scale factor tilt angle Ū average wind speed β V_{hub} gamma function wind speed at a turbine hub height air density at hub height V_{anem} wind speed at anemometer height ρ_{hub} battery round trip efficiency Z_{hub} wind turbine hub height $\eta_{B,rt}$ battery charge efficiency mean global horizontal radiation $G\overline{H}R$ $\eta_{B,ch\,\mathrm{arg}\,e}$ converter efficiency

 η_C

available energy in the battery

total capacity of the battery bank

 Q_1

 Q_{max}

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