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Doctoral Dissertation

Doctoral Program in Mechanical Engineering (34th cycle)

Setting-up the decarbonisation of islands: models and technologies for the energy transition

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Politecnico di Torino

2022

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2022

* This dissertation is presented in partial fulfillment of the requirements for **Ph.D. degree** in the Graduate School of Politecnico di Torino (ScuDo).

Setting-up the decarbonisation of islands: models and technologies for the energy transition

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Climate change and geopolitical uncertainties are urging the achievement of a clean, secure and affordable energy supply. However, there are considerable technical and policy challenges on the path to sustainable energy concerning the complexity of managing high share of electricity from renewable energy sources. Such challenges can be faced by means of energy modelling and planning. Islands, due to their expensive and fossil fuel-based energy mix, the favorable availability of offshore renewable energy sources and valuable environmental heritage, are ideal test-beds for achieving a fully sustainable decarbonisation. The aim of this dissertation is to improve the modelling of insular energy systems to support technical and political decisions in the field of the energy transition. Multi-year optimisation-based energy models are developed for this purpose using the mixed-integer linear programming technique. First, the effects of uncertainties in the adoption of user-scale technologies on energy system evolution are assessed. The diffusion of decentralised photovoltaics is highlighted as a key factor that, if properly addressed, may lead to over 49% CO₂ emissions reduction with respect to the business as usual scenario. Moreover, it is worth noting that long-term models are weak in describing a high share of renewables, as representative days are commonly used to limit the computational burden. Therefore, a new temporal framework based on clustered and interconnected representative days is proposed. It is demonstrated that the revised approach leads to an underestimation of the total system cost lower than 5% when 24 representative days are used, compared to the ~35% of the underestimation resulting from the conventional approach. A 100% renewable insular system is also examined to investigate the role of different energy storage technologies, comparing hydrogen-based storage and Li-ion batteries. It is highlighted that scenarios without hydrogen storage could lead to a ~155% increase in the net present cost of the system: this result underlines the need to further develop storage technologies in which the energy size is not bound to the power size. In order to facilitate the inclusion of offshore renewables in energy models and strategies, a novel platform for assessing the productivity of wave energy converters is proposed. Finally, the importance of appropriate spatial planning for improving public energy policies at the local level is discussed. The work develops through the case study of the Isle of Pantelleria (Sicily) and presents methodological advances that contribute to enhance the modelling and planning of large-scale energy systems.

Nomenclature

Symbols

δ	pitching angle
η	wave elevation
λ	wavelength
ω	angular frequency
Φ	velocity potential
ρ	air density
A	Weibull scale parameter
B_d	buoy draft
B_r	buoy radius
B_{PTO}	PTO damping
c	phase velocity
C_f	corrective feature coefficient
C_p	power coefficient
C_{st}	solar thermal coefficient
Dir_m	mean wave direction
E_y	annual productivity yield
G	solar irradiation
G	total solar irradiance

g	gravity acceleration constant
G_b	beam (direct) solar irradiance
G_d	diffuse sky solar irradiance
GCR	ground-cover ratio
H_s	significant wave height
k	Weibull shape factor
k	wavenumber
K_{PTO}	PTO stiffness
p	pressure
R_{ra/PV_p}	total roof area-to-PV power ratio
$RE_{OF,conf}^{\pm}$	relative error in the total system cost for a certain configuration
S_w	wetted surface
S_{feas}	feasible surface
S_{leg}	legal surface
S_{suit}	suitable surface
T_e	wave energy period
v	wind velocity
V_w	wetted volume
z	user-defined height for wind speed calculation
z_0	roughness length
z_{max}	maximum vertical displacement

Acronyms / Abbreviations

BATT batteries

BATT_s battery storage

BATT_t battery technology

BEM boundary element method

BIO_EXTR biomass extraction

CAPEX capital expenditures

CCS capital costs of storage

CCs capital costs

CETA Clean Energy Transition Agenda

CFD Computational Fluid Dynamics

conf configuration

COP Conference of Parties

CTRN numerical technical regional map

DESALT desalinators

DIESEL_IMP diesel import

DIESEL_PP diesel power plant

DIST_GRID electricity distribution grid

DOF degree-of-freedom

DSM digital surface model

DSO distribution system operator

DTM digital terrain model

ECMWF European Centre for Medium-Range Forecasts

EES electrical energy storage

EL_STO electricity storage

ELC electricity

ELY electrolyser

EMODNet European Marine Observation and Data Network

ERD entity relation diagram

ES energy system

ESCO energy services company

ESM energy system model

ETS emission trading system

EU European Union

EV electric vehicle

FC fuel cell

FCs fixed costs

FFT fast Fourier transform

FOWT floating offshore wind turbines

GHGs greenhouse gases

GIS geographic information system

GSL_IMP gasoline import

HRES hybrid renewable energy systems

HT hydrogen tank

HVAC heating, ventilation and air conditioning

HYB hybrid

IBA Important Bird and Biodiversity Area

IPCC International Panel on Climate Change

IRENA International Renewable Energy Agency

LCOE levelized cost of energy

LP linear programming

LPG liquefied petroleum gas

LPG_IMP liquified petroleum gas import

MILP mixed-integer linear programming

MSW municipal solid waste

NEW novel method

NPC net present cost

OB only-battery

OF objective function

OFMSW organic fraction of municipal solid waste

OH only-hydrogen

OPEX operating expenditures

OSWEC Oscillating Surge Wave Energy Converter

p.u. per unit

PAI Piano stralcio per l'assetto idrogeologico

PEM proton exchange membrane

PeWEC Pendulum Wave Energy Converter

PTO power take off

PtP power-to-power

PtX power-to-X

PV photovoltaic

PV_CENTR centralised photovoltaic power plants

RDs representative days

RES renewable energy sources

RMS root mean square

SAC Special Areas of Conservation

SCI Sites of Community Importance

SEBE Solar Energy on Building Envelopes

SIDS Small Island Developing States

SOC state-of-charge

SPA Special Protection Areas

SWAN Simulating WAVes Nearshore

TLP tension leg platform

TRAD traditional method

TRL technology readiness level

TSO Transmission System Operator

UMEP Urban Multi-scale Environmental Predictor

VC variable costs

VRES Variable Renewable Energy Sources

WAsP Wind Atlas Analysis and Application Program

WAT_STO water storage

WEC wave energy converter

WPD Wind Power Density

WT onshore wind turbines

ZEA Environmental Economic Zone