Lecture Notes in Energy 100

Akilu Yunusa-Kaltungo *Editor*

Key Themes in Energy Management

A Compilation of Current Practices, Research Advances, and Future Opportunities

Springer

Lecture Notes in Energy

Volume 100

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Editor

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ISSN 2195-1284 ISSN 2195-1292 (electronic)
Lecture Notes in Energy
ISBN 978-3-031-58085-7 ISBN 978-3-031-58086-4 (eBook)
https://doi.org/10.1007/978-3-031-58086-4

I dedicate this book to my family, especially my lovely wife (Rukaiyatu Mohammed Jungudo) and kids (Yunusa Akilu, Hassana Akilu, and Muhammad Akilu).

Foreword

Key Themes in Energy Management: A Compilation of Current Practices, Research Advances, and Future Opportunities is a broad and eclectic collection of chapters edited by Dr. Akilu Yunusa-Kaltungo that moves through some of the pertinent issues currently facing academics and wider stakeholders across the energy system. What is striking about the book is the wide range of country contexts and different disciplinary experts represented within the texts, covering important topics from energy efficiency in domestic buildings through to managing the energy transition within industrial assets based in oil-based economies. Dr. Yunusa-Kaltungo is particularly well-placed to assemble this compilation, given his own diverse energy-focused research interests and engineering expertise taken from both industrial and academic settings. His insights from decarbonising high-energy industrial operations, through to using machine learning-based fault detection and diagnosis methods, are applied here to ensure that the collection presents learning from across the worlds of health and safety management and climate change mitigation for the benefit of energy management more broadly.

The book is timely given the unfortunate slow pace with which the world is facing up to the challenges posed by both mitigating climate change and adapting to its impacts and challenges that require concerted urgent attention, new thinking, and innovative solutions in the field of energy management. Energy transition and transformation are easy to say but can only be achieved if all sectors begin to embed new practices, new ways of managing energy, and new energy-smart designs, whilst at the same time, shifting to renewable energy sources. An undeniable fact within the climate mitigation debate is that the lower the energy consumed, the easier an energy transition will be—given the extent to which energy infrastructure must be transformed. However, moving towards widespread use of lower energy technologies and practices requires deep thinking, new research, and a systems perspective that can be applied to different industrial, commercial, and domestic settings alike. The climate change mitigation challenge provides an imperative for focused strategies to manage and reduce energy consumption during the low carbon transition, whether at the point of use, across the energy system, or within the energy industry itself. At

the same time, the implications for the energy system of new and more diverse low-carbon supply-side technologies will need to be complimented by emerging smart energy management innovations. *Key Themes in Energy Management* tackles many of these problems and issues, whilst drawing attention to some of the engineering and societal realities of what a low-carbon energy transformation means for different parts of the world.

The book brings the chapters together under five parts: (i) Renewable and Alternative Energy Sources; (ii) Energy Transition, Energy Efficiency, and Energy Utilisation; (iii) Energy Consumption Prediction and Energy Optimisation in Buildings; (iv) Key Technologies for Smart Energy Management; and (v) Maintenance and Asset Management of Energy Systems. The authors are not only drawing on a very wide span of engineering and computational disciplines, but also bring forward understanding from the social sciences, including governance, justice, and public health. What is clear from the range of topics is that the challenges are dynamic in nature and at play on different timescales depending on where in the world the focus may be. Access to energy resources to improve well-being, inward country investment into energy infrastructure, and the heavy economic reliance in some nations on conventional energy resources, all play a role in the pace of change and the position in time along a pathway to a fully decarbonised system. Although some of the chapters focus on research that helps to reduce energy consumption within high carbon assets, others are digging into the challenges that the world needs to overcome as our energy supply system increasingly adopts more renewable and smart technologies or responds to growth in new electricity demands, such as from electric vehicles.

Naturally, different country contexts will matter when it comes to the application of research insights and innovations. Countries are at different stages of development, have different economic reliance on existing high-carbon coal, oil, and gas infrastructure, and different cultural and social aspects to be understood and worked with if the transition is to accelerate. Whilst no book could present a full range of global perspectives, *Key Themes in Energy Management* has sufficiently diverse research insights to allow the reader to consider how energy management challenges in a range of sub-Saharan African countries may be contrasted with those within other highly industrialised settings. It also pays particular attention to some of the methods and tools that are increasingly required to support decision-makers in delivering sound energy management choices. Whether this is to optimise renewable energy capacity in Africa to alleviate poverty or design buildings and choose building materials that minimise energy from the outset. The research captured within the collection offers academics and decision-making stakeholders new avenues and strategies to deliver urgently needed advances across the energy spectrum.

The world is starting to face up to the need for a rapid, low-carbon energy transformation. During the transition, energy assets will need to be managed and decarbonised, energy reduction brought front and centre into engineering design, and difficult decisions will be needed to move more quickly away from existing energy assets than originally anticipated. *Key Themes in Energy Management* sheds light on some of the pertinent challenges ahead and interrogates tools and methods needed

for good energy decision making that will serve to equip energy experts with insights needed to deliver a global energy transformation in a timely fashion.

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Preface

Predictions about the rapid depletion of some traditional energy resources such as fossil fuels, coupled with the threats that they pose on the environment, have necessitated urgent implementation of effective energy management strategies. Additionally, the wide distribution of energy resources across different regions of the globe (especially among developing countries) has always been considered positive as it aids accessibility and reduces monopoly. However, the persistent spate of natural and man-made disasters such as wars, ethnic clashes, and insurgency in several of these regions has further compounded the challenges of ensuring that clean energy is truly affordable, reliable, and sustainable for all.

Based on these premises, it would seem logical to direct thoughts towards creating a truly holistic strategic plan for managing energy across the globe. Ideally, such a plan should initially encompass approaches that would ease the implementation of resilient energy policies, as well as identifying possible barriers and enhancers to such policies. This is by no means a simple process as it entails political, economic, societal, technological, economic, and legal factors that are often intertwined. Therefore, *Key Themes in Energy Management: A Compilation of Current Practices, Research Advances, and Future Opportunities* covers a holistic plethora of topics related to the theory and practice of energy management and its associated technologies, which will serve as core text on a wide spectrum of programmes, ranging from very technical STEM-based programmes to management and multidisciplinary programmes that feed into the wider field of energy management.

The 25 chapters of the book are grouped under the following parts, which makes it unique and easy to comprehend:

- Part One: Renewable and Alternative Energy Sources
- Part Two: Energy Transition, Energy Efficiency, and Energy Utilisation
- Part Three: Energy Consumption Prediction and Energy Optimisation in Buildings
- Part Four: Key Technologies for Smart Energy Management
- Part Five: Maintenance and Asset Management of Energy Systems

The chapters that make-up Part One focus on the description of various renewable and alternative energy sources that are peculiar to different regions across the world.

Some of the chapters describe the core characteristics (including their availability, geographical locations, and sustainability) of such renewable and alternative energy sources, while other chapters conducted detailed techno-economic assessments via case studies. In Part Two however, the contributing chapters mainly focused on creating an understanding of how to efficiently migrate towards renewable energy sources and the peculiar challenges that such migrations might encounter in different regions of the world, especially the developing countries. Buildings are fundamental to the existence of people, but they also account for enormous proportions of global energy consumption, which is predicted to further rise owing to the proliferation of global population and the need for buildings reconstructions/upgrades following natural and man-made disasters. Therefore, Part Three presents emerging mechanisms for optimising energy consumption in buildings. However, any energy optimisation strategy must be preceded by the availability of accurate energy demand information. Hence, this part also presents research related to the use of trending techniques such artificial intelligence and machine learning to determine the energy demand of buildings, including those with limited data sets such as historic buildings that may not be furnished with sophisticated building energy management systems.

Part Four explores crucial mechanisms for realising smart energy management, including power sharing as a means of minimising energy wastage and alleviating energy poverty. Regardless of whether energy is sourced from conventional, alternative, renewable, or hybrid sources, its generation and distribution rely heavily on physical industrial assets (PIAs) which must be always kept reliable, to optimise the embodied energy associated with the downstream processes. Therefore, Part Five combines chapters that discuss the appropriateness of different maintenance strategies on the reliability of different energy systems, including an assessment of how much cultures enable or impede the selection and implementation of such strategies. Furthermore, this theme demonstrates that it might be wishful and counterproductive to push hard for a universal abandonment of traditional energy sources globally, due to obvious disparities in wealth across different regions of the world. It might therefore be reasonable to adopt a transition rate that adequately reflects the capabilities of the concerned regions and to emphasise the implementation of asset management policies that guarantee the reliability of PIAs.

This book uniquely addresses the gap in current body of knowledge by providing multidisciplinary perspectives and professional practices in energy management globally, which will help its wide readership (including regulators, professionals, researchers, policy makers, and students) to comprehend a plethora of energy-related issues and opportunities. Besides its primary aim of compiling current practices, research advances, and future opportunities in the field of energy management globally, the book also serves as a conduit for enhancing the ability of academics and industry professionals to jointly create impactful scholarly articles within the wider field of energy management studies.

The editor would like to specially thank the 65 contributing authors (covering over 30 countries and 6 continents) for their efforts towards making this book project a global success. Special gratitude must also be extended to Dr. Anisa Kabir Abdulfatah, Dr. David Junior Gilbert, Dr. Aliyu M. Aliyu, Dr. Abubakar Abdullahi Mas'ud,

Dr. Fatima Madugu, Dr. Shaikha AlSanad, Dr. Ashraf Alghanmi, Mr. Amirhossein Balali, Dr. Qingyao Qiao, Dr. Nabila Ahmed Rufa'I, Prof. Wee Shing Koh, Ms. Ziqing Xu, Dr. Aisha Sa'ad, Dr. Naa Adjeley Asiboe-Mensah Doamekpor, Dr. Saeed Reza Mohandes, and Dr. Ndubuisi Uchechukwu Okereke, for their persistence on quality, robustness, relevance, and reliability of the information presented in the chapters that make-up this book through their independent reviews.

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Acknowledgements The authors wish to express their gratitude to the company employees who participated in the different workshops and meetings and completed the various surveys questionnaires. This project could not have been realized without their good predisposition and commitment. We also want to highlight the interest shown and open-mindedness of the various company's sectors involved during every step of the initiative.

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Akilu Yunusa-Kaltungo (Ph.D., FIMechE, CEng, FHEA) is Reader (Associate Professor) in Reliability and Maintenance Engineering, as well as Head of Education for the School of Engineering at The University of Manchester. He has a diverse range of research specialties, owing to his blend of academic and industrial experiences. Some of the areas in which Akilu has developed notable international reputation include improving Occupational Safety and Health Performance across high-risk sectors, decarbonisation of high-energy industrial operations, building energy consumption prediction and optimisation, vibration-based condition monitoring of industrial machines, machine learning-based faults detection and diagnosis, construction projects risk classification, industrial asset management and reliability, etc., through collaborations with reputable research-focused institutions such as Health and Safety Executive (HSE-UK), Lloyd's Register Foundation (LRF), InnovateUK, and EPSRC. He has supported the realisation of over GBP £1.6 million external research funding, either as Principal Investigator (PI) or Co-investigator (Co-I). He has also generated over 140 technical publications in the form of high-impact journal articles, peer-reviewed conference articles, textbooks, book chapters, government commissioned reports, and professional articles. He is also Editor of *Key Themes in Energy Management: A Compilation of Current Practices, Research Advances, and Future Opportunities.*

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Abbreviations

AAN	Artificial Neural Network
AC	Alternating Current
ACH	Air change per hour
ADA	Advanced Distribution Automation
AEC	Available energy capacity
AFREA	Africa Renewable Energy Access Program
AGHA	African Green Hydrogen Alliance
AHP	Analytic Hierarchy Process
AHU	Air Handling Unit
AI	Artificial Intelligence
ALARP	As Low as Reasonably Practicable
AM	Asset Management
AMI	Advanced Metering Infrastructure
AMS	Asset Management System
ANG	Associated Natural Gas
ANN	Artificial Neural Network
ANP	Analytic Network Process
AOGWs	Abandoned oil and gas wells
ARAS	Additive Ratio Assessment
ARIMA	Auto regressive integrated moving average
ASTM	American society for testing and material
ATM	Atmospheres
ATR	Auto Thermal Reforming
BC	Black carbon
BCG	Boston Consulting Group
BEIA	Biomass Energy Initiative for Africa
BEM	Building energy modelling
BESS	Battery energy storage systems
BEV	Battery electrical vehicle
BMS	Building Management Systems
BOEC	Optimal operational energy consumption

BSS	Battery switching system
BWM	Best-Worst Method
C&I	Commercial And Industrial
C_b	Battery capacity
CC	Cycle Charging
CCGT	Combined Cycle Gas Turbine
C_{cm}	Cost of corrective maintenance
CCP	Climate change potential
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Sequestration
CDF	Cumulative distribution function
CE	Circular economy
CED	Cumulative energy demand
CEIF	Clean Energy Investment Framework
CF	Condenser Fouling
CFD	Computational fluid dynamics
CH_4	Methane
CHAdEMO DC	Charge de more direct current
CI	Consistency Index
CMMS	Computerized Maintenance Management System
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
COCOSO	Combined Compromise Solution
CODAS	Combinative Distance-based Assessment
COPRAS	Complex Proportional Assessment
COVID-19	Coronavirus disease 2019
C_{pm}	Cost of preventive maintenance
CR	Consistency Ratio
CRITIC	Criteria Importance Through Intercriteria Correlation
CRU	Commission for Regulation of Utilities
CSP	Concentrated solar power
CU	Condenser units
D	Diameter
DAO	Decentralised Autonomous Organisation
DC	Direct Current
DCS	District cooling systems
DEMATEL	Decision-Making Trial and Evaluation Laboratory
DER	Distributed Energy Resource
DES	Distributed Energy Systems
DF	Dirty Filter
DiG	Diesel Generator
DG	Distributed generation
DHW	Domestic Hot Water
DISCOS	Distribution Companies

DNN	Deep neural networks
DoD	Depth of discharge
DPoS	Delegated Proof of Work
DR	Demand Response
DSM	Demand-Side Management
DTA	Thermal Analysis
ECG	Electricity Company of Ghana
ECN	Energy Commission of Nigeria
EDAS	Evaluation based on Distance from Average Solution
EFA	Exploratory Factor Analysis
EGS	Enhanced geothermal system
ELECTRE	Elimination and Choice Expressing Reality
EM	Energy Management
EMS	Energy Management System
EO	Equilibrium Optimizer
EOL	End-of-life
EOR	Enhanced Oil Recovery
EPC	Error Producing Conditions
EPW	Energy Plus Weather
ES	Energy Simulation
ESG	Environmental, Social and Governance
ESMAP	Energy Sector Management Assistance Program
ESOM	Energy System Optimisation Model
ESS	Energy Storage System
EU	European Union
EUI	Energy Use Intensity
EV	Electrical vehicle
FC	Fuel Cell
FCP	Freshwater consumption potential
FDP	Fossil depletion potential
FEP	Freshwater eutrophication potential
FETP	Freshwater ecotoxicity potential
FFD	Fault Detection and Diagnosis
FM	Failure Mode
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FMP	Federal Ministry of Power
FN	False-Negative value
FP	False-Positive value
FPMFP	Fine particulate matter formation potential
FTA	Fault Tree Analysis
GC	Global Criterion
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GECF	Gas Exporting Countries Forum

GEO_{bau}	Business-as-usual geothermal power plant
GHG	Greenhouse Gas
GLOBE	Global Leadership and Organizational Behaviour Effectiveness
GM:2021	Singapore Green Mark 2021
GNI	Gas Networks Ireland
GOA	Grasshopper Optimisation Algorithm
GP	Global Programming
GPPs	Geothermal power plants
GPS	Global positioning system
GRA	Grey Relational Analysis
GTL	Gas To Liquid
GTM	Gas To Methanol
GTP	Gas To Pipeline
GTT	General Task Types
GTW	Gas To Wire
GW	Giga Watt
GWEC	Global Wind Energy Council
GWh	Gigawatt hour
H	Production horizon
H/C	Hydrogen Carbon Ratio
H_2	Hydrogen
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HDB	Housing Development Board, Singapore
HDI	Human development index
HEART	Human Error Assessment and Reduction Technique
HEP	Human Error Probability
HFACS	Human Factors Analysis and Classification System
HFE	Human Factors Engineering
HIA	Health Impact Assessment
HOMER	Hybrid Optimisation of Multiple Energy Resources
HRA	Human Reliability Assessment
HRES	Hybrid Renewable Energy System
HRO	High Reliability Organization
HTF	Heat Transfer Fluid
HTP, cancer	Human toxicity potential, cancer effect
HTP, non-cancer	Human toxicity potential, non-cancer effect
HVAC	Heating ventilation and air conditioning
HySA	Hydrogen South Africa
IAOA	Improved Archimedes Optimization Algorithm
IBDR	Incentive-Based DR
ICP	Interactive Compromise Programming
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IEA	International Energy Agency

IOGP	International Association of Oil & Gas Producers
IRENA	International Renewable Energy Agency
IRP	Ionizing radiation potential
ISO	International Organization for Standardization
IT2FS	Interval type-2 fuzzy set
JEDCO	Jos electricity distribution company
KISR	Kuwait Institute for Scientific Research
KMO	Kaiser-Meyer-Olkin
kNN	k nearest neighbour
kPa	Kilopascal
kV	Kilovolt
kW	Kilowatt
kWe	Kilowatt Electric
kWh	Kilowatt-hour
kWp	Kilowatt Peak Power
LCA	Life cycle assessment
LCC	Life cycle cost
LCCR	Optimal life cycle carbon reduction
LCD	Occupancy Sensor Time Delay
LCEB	Optimal life cycle economic benefit
LCOE	Levelised Cost of Energy
LED	Light emitting diode
LEED	Leadership in Energy and Environmental Design
LF	Load Flowing
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LR	Linear regression
LSTM	Long Short-Term Memory
LUP	Land use potential
m	Meter
m^2	Squared meter
MABAC	Multi-Attributive Border Approximation Area Comparison
MADM	Multiple Attribute Decision-Making
MAH	Major Accident Hazard
MARCOS	Measurement Alternatives and Ranking According to Compromise Solution
MAUT	Multi Attribute Utility Theory
MCDA	Multicriteria Decision Analysis
MCDM	Multiple Criteria Decision-Making
MDP	Metal depletion potential
MEET	Multidisciplinary and multi-context demonstration of enhanced geothermal systems exploration and exploitation techniques and potentials
MEh	Megawatt hour
MEP	Marine eutrophication potential

METP	Marine ecotoxicity potential
MEW	Ministry of Electricity and Water
MG	Microgrid Technology
MGA	Modelling to Generate Alternative
MJ	Mega joules
ML	Machine learning
MLP	Multi-Level Perspective
MODM	Multiple Objective Decision-Making
MOORA	Multi-Objective Optimization on the basis of Ratio Analysis
MOP	Maximum Operating Pressure
MOPSO	Multi-objective particle swarm optimization
MPPT	Maximum power point tracker
MSME	Micro, Small and Medium Enterprises
mt/yr	Millions of tons per year
$MtCO_2e$	Metric tons of Carbon (iv) Oxide equivalent
MTI	Ministry of Trade and Industry
MW	Megawatts
MWe	Megawatt electric
MWth	Megawatt thermal
N	Number of preventive maintenance
N*	Optimal number of maintenance
N_2	Nitrogen
NCC	National Control Centre
NDA	Negative Distance from Average
NEEAP	The National Energy Efficiency Action Plan
NEMP	National Energy Master Plan
NEP	National Energy Policy
NGH	Natural Gas To Hydrates
NGRP	Natural Gas Re-injection Process
NGV	Natural Gas Vehicle
NH_3	Ammonia
NMR	Nuclear Magnetic Resonance
NOx	Nitrogen oxides
NPC	Net Present Cost
N_{pv}	Number of PV panels
NREAP	National Renewable-Energy Action Plan
NREMP	The National Renewable Energy Master Plan
NSGA-II	Non-dominated Sorting Genetic Algorithm II
NSGA-III	Non-dominated Sorting Genetic Algorithm III
NTH	Natural Gas To Hydrogen
NTS	Non-Technical Skills
NV	Normalised value
NZCB/NZEB	Net Zero Carbon/Energy Buildings
O&G	Oil and Gas
O&M	Operations and maintenance

OCSVM	One Class Support Vector Machine
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of the Petroleum Exporting Countries
ORC	Organic Rankine cycle
ORESTE	Organísation, aangement et Synthèse de données relarionnelles
P	Pressure
P2G	Peer-to-Grid
P2P	Peer-to-peer
PBDR	Price-Based DR
PCM	Phase Changing Material
PD^2	Hazard Factor
PDA	Positive Distance from Average
PE	Polyethylene
PEV	Plug in electrical vehicle
PHC	Primary Health Care Centres
PHCN	Power Holding Company of Nigeria
PHEV	Plug in hybrid electrical vehicle
P_L	Load power required
PoA	Proportion of Affect
PoET	Proof-of-Elapsed Time
PoF	Probability of Failure
POFEP	Photochemical ozone formation, ecosystems potential
POFHP	Photochemical ozone formation, human health potential
PoS	Proof of Stake
PoW	Proof of Work
POX	Partial Oxidation
PPP	Public-Private Partnership
P_{pv}	Power generated from PV panels
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta Analyses
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PV	Photovoltaics
QoS	Quality of Service
QRA	Quantitative Risk Assessment
R	Residual
R&D	Research and Development
R*	Reliability threshold
RAC	Refrigeration and air conditioning
RANS	Reynolds-averaged Navier-Stokes
RE	Renewable energy
RECs	Renewable Energy Credits
REDG	Renewable energy distributed generation
REIPPPP	South Africa's Renewable Energy Independent Power Producer Procurement Programme

RES	Renewable energy source
RF	Random forest
RFPs	Request for Proposals
$R\text{-}GEO_{double}$	Repurposed two completely abandoned oil and gas wells
$R\text{-}GEO_{semi}$	Repurposed semi-abandoned oil and gas wells
$R\text{-}GEO_{single}$	Repurposed single completely abandoned oil and gas well
ROI	Return of Investment
R_{pv}	Reliability of PV system
R-value	Thermal Resistance
S	Seasonal Components
SAC	Split-unit air conditioning
SAF	Sustainable aviation fuel
SAM	System advisor model
SARIMAX	Seasonal Autoregressive Integrated Moving Average
SAW	Simple Additive Weighting
SCA	Solar Collector Assemblies
SCADA	Supervisory Control and Data Acquisition
SCE	Solar collector elements
SDGs	Sustainable development goals
SDN	Software-Defined Networking
SEforAll	Sustainable Energy for All
SES	Smart Energy System
SG	Smart Grid
SGS	Steam Generation System
SHS	Solar Home Systems
SIMPLE	Semi-implicit method for pressure-linked equations
SMART	Simple Multi-Attribute Rating Technique
SMR	Steam methane reforming
SMS	Smart Metering System
SMYS	Specified Minimum Yield Stress
SOC	State of Charge
SODP	Stratospheric ozone depletion potential
SoS	Security of Supply
SRES	Shared Renewable Energy System
SSA	Sub-Saharan Africa
SSD	Statistical Seasonal Decomposition
STATCOM	Static synchronous compensator
STL	Seasonal-Trend decomposition using Loess
STM	Security Threat Mitigation
STS	Socio-Technical System
SVM	Support vector machine
SWARA	Step-wise Weight Assessment Ratio Analysis
T	Trend Cycles
t	Wall Thickness
T&G	Tongue and Groove

T1F	Type-1 Fuzzy
T2F	Type-2 Fuzzy
T2FS	Type-2 fuzzy set
TAP	Terrestrial acidification potential
Tcf	Trillion cubic feet
TES	TEs
TETP	Terrestrial ecotoxicity potential
TMY	Typical meteorological year
TN	True-Negative value
TO	Thermostat Offset
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TP	True-Positive value
TW	Terawatt
TWh	Terawatt hour
UHI	Urban heat island
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Program
UNECA	United Nations Economic Commission for Africa
U-value	Thermal Transmittance
V2G	Vehicle to grid
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V_b	Battery voltage
VIKOR	Viekriterijumsko Kompromisno Rangiranje
W	Watt
W/m^2	Watts per meter-square
W/m^2 K	Watts per meter-square-kelvin
W/zone	Watt per zone
WASPAS	Weighted Aggregated Sum Product Assessment
Wh/kg	Watt-hour per kilogram
WHO	World Health Organization
WoS	Web of Science
WPM	Weighted Product Model
WSM	Weighted Sum Model
WT	Wind Turbine
WWR	Window to Wall Ratio
XGBoost	Extreme Gradient Boosting
ZEM2All	Zero emissions mobility to all