

# **Energy and water supply systems in remote regions considering renewable energies and seawater desalination**

**Dipl.-Ing. Kristina Bognar**

von der Fakultät III - Prozesswissenschaften  
der Technischen Universität Berlin  
zur Erlangung des akademischen Grades

Doktorin der Ingenieurwissenschaften  
- Dr.-Ing. -

genehmigte Dissertation

Promotionsausschuss:  
Vorsitzender: Prof. Dr.-Ing. Felix Ziegler  
Berichter: Prof. Dr. Frank Behrendt  
Berichter: Prof. Dr. Ottmar Edenhofer

Tag der wissenschaftlichen Aussprache: 22. März 2013

Berlin, 2013  
D 83



Schriftenreihe der Reiner Lemoine-Stiftung

**Kristina Bognar**

**Energy and water supply systems in remote regions  
considering renewable energies and  
seawater desalination**

D 83 (Diss. TU Berlin)

Shaker Verlag  
Aachen 2013

**Bibliographic information published by the Deutsche Nationalbibliothek**

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Berlin, Techn. Univ., Diss., 2013

Copyright Shaker Verlag 2013

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

Printed in Germany.

ISBN 978-3-8440-1933-9

ISSN 2193-7575

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen

Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9

Internet: [www.shaker.de](http://www.shaker.de) • e-mail: [info@shaker.de](mailto:info@shaker.de)

## Abstract

Islands and remote regions often depend on the import of fossil fuels for power generation. Due to the combined effect of high oil prices and transportation costs, energy supply systems based on renewable energies are already able to compete with fossil-fuel based supply systems successfully. A limiting factor for development in arid regions is the fresh water scarcity resulting from low natural water stocks and excessive groundwater usage.

How seawater desalination and remote island-grids with a high share of renewable energies can benefit each other, is still not sufficiently investigated. To answer this and related research questions, a model for optimizing self-sufficient energy and water supply systems has been developed, using the modeling language GAMS. Based on sets of hourly data various scenarios implementing energy conversion technologies, energy storage systems and desalination processes have been simulated and techno-economic optimizations accomplished. A global sensitivity and real option analysis addresses optimal system designs and finance strategies taking uncertain demand and price developments into consideration.

Key findings reflect that the integration of renewable energies is beneficial. On the Cape Verde island Brava, that has been chosen as a case study in the framework of this research, power is currently provided by diesel generators at prices of 0.25 to 0.31 €/kWh and water is sold for 2.35 and 4.93 €/m<sup>3</sup> depending on the quantity. With the recommended wind-battery-diesel and desalination supply system specific electricity costs ranging from 0.15 to 0.21 €/kWh and water costs of 1.53 €/m<sup>3</sup> are achievable.

Effects of integrating desalination as a dynamic load complementing consumer induced load curves in stochastically fluctuating energy systems are analyzed as well as the respective benefits highlighted: Excess wind energy, fuel consumption, and required energy storage capacities can be minimized resulting in lower specific electricity costs. From five thermally and electrically driven desalination processes a variable operating reverse osmosis unit is the most flexible process facing intermittent and part-load operation.

To determine the technological and economic robustness of such an energy and water supply system the most sensitive parameters are identified and various analyses performed. The approaches that have been introduced and respectively the results derived for the Cape Verde island Brava have been further underlined by investigating comparable island-grids and are transferable to a global perspective.



## Zusammenfassung

Inseln und abgelegene Regionen sind für die Energieversorgung häufig auf den Import fossiler Energieträger angewiesen. Auf Grund hoher Diesel- und Transportkosten rechnen sich Versorgungssysteme basierend auf erneuerbaren Energien wirtschaftlich schon heute. Ein limitierender Faktor für die Entwicklung arider Regionen ist die Wasserknappheit, die in der Regel auf geringe natürliche Wasservorkommen und die Übernutzung des Grundwassers zurückzuführen ist.

In wie weit Meerwasserentsalzungsanlagen in Inselnetzen mit einem hohen Anteil erneuerbarer Energien energetische und ökonomische Vorteile bringen kann, ist noch ungenügend untersucht. Um diese und ähnliche Forschungsfragen beantworten zu können, wurde ein Modell zur Optimierung von autarken Energie- und Wasserversorgungskonzepten in der Modellierungsumgebung GAMS entwickelt. Basierend auf stündlich aufgelösten Nachfrage-, Windgeschwindigkeits- und Solareinstrahlungsdaten werden Szenarien technisch-ökonomisch und ökologisch optimiert, in denen verschiedene Umwandlungstechniken regenerativer und fossiler Energien, thermische sowie elektrische Energiespeicher und Entsalzungsprozesse miteinander kombiniert werden. Eine globale Sensitivitäts- und auch Realoptions-Analyse beschäftigt sich mit Effekten von Nachfrageveränderungen, preislichen sowie technologischen Unsicherheiten und Ihren Auswirkungen auf ein langfristig robustes Versorgungskonzept.

Es wird gezeigt, dass die Integration von erneuerbaren Energien und der Meerwasserentsalzung in allen untersuchten Inselnetzen vorteilhaft sein kann. Gegenstand der Untersuchung ist die kapverdische Insel Brava, wo der von Dieselmotoren generierte Strom derzeit 0,25 bis 0,31 €/kWh kostet und Trinkwasserpreise bei 2,35 bis 4,93 €/m<sup>3</sup> liegen. Unabhängig von der Preispolitik können mit dem errechneten Konzept spezifische Stromkosten von 0,15 bis 0,21 €/kWh und Wasserkosten von 1,53 €/m<sup>3</sup> erreicht werden.

Weitere Ergebnisse sind u.a., dass eine Meerwasserentsalzungsanlage bei stark fluktuierenden Versorgungsstrukturen als dynamische Last Vorteile bringen kann: Überschüssige Windenergie, der Dieselverbrauch sowie die Kapazität von Stromspeichern können gesenkt werden und damit auch die spezifischen Stromkosten. Von den fünf betrachteten Entsalzungstechnologien ist trotz der sensiblen Membrane die variabel betriebene Umkehrsmose-Anlage die robusteste im Umgang mit unstetiger, anteiliger und abreißender Energieversorgung.

Um die technologische und ökonomische Verlässlichkeit und Optimalität des Versorgungskonzepts prüfen zu können, werden die sensibelsten Parameter bestimmt und deren Auswirkungen in weitreichenden Sensitivitätsanalysen untersucht. Vor gestellte Ansätze und Ergebnisse können durch die Betrachtung von ähnlichen Inselnetzen bestätigt und daher auch global auf weitere Regionen übertragen werden.



# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Motivation . . . . .	1
1.2	Research objective . . . . .	3
1.3	Structure of thesis . . . . .	4
<b>2</b>	<b>Background</b>	<b>5</b>
2.1	Energy supply structures . . . . .	5
2.1.1	Demand Side Management . . . . .	6
2.1.2	Renewable power generation in island grids . . . . .	7
2.2	Renewable energy technologies . . . . .	9
2.2.1	Photovoltaics . . . . .	9
2.2.2	Concentrated Solar Power . . . . .	10
2.2.3	Wind energy converters . . . . .	13
2.3	Energy storage systems . . . . .	14
2.3.1	Thermal energy storage systems . . . . .	14
2.3.2	Electricity storage systems . . . . .	16
2.4	Backup system . . . . .	21
2.5	Seawater desalination in remote regions . . . . .	22
2.5.1	Basics of water . . . . .	22
2.5.2	Desalination processes . . . . .	24
2.5.3	Variable operating desalination . . . . .	30
2.5.4	Desalination powered by renewable energies . . . . .	31
2.6	Small Island Developing States . . . . .	33

<b>3 Methodology</b>	<b>36</b>
3.1 Simulation of energy systems . . . . .	36
3.2 Simulation of desalination units . . . . .	39
3.3 Optimization approach . . . . .	41
3.3.1 GAMS/OSICplex . . . . .	42
3.3.2 Characteristics of developed program . . . . .	43
3.4 Sensitivity analysis . . . . .	47
3.5 Real option analysis . . . . .	48
3.6 Ecological constraints within the model . . . . .	51
<b>4 Model</b>	<b>53</b>
4.1 Objective function and main constraints . . . . .	54
4.2 Modeling total costs . . . . .	57
4.3 Modeling photovoltaic energy generation systems . . . . .	58
4.3.1 Modeling energy flows (PV) . . . . .	58
4.3.2 Modeling total costs (PV) . . . . .	58
4.4 Modeling concentrated solar power systems . . . . .	59
4.4.1 Modeling energy flows (CSP) . . . . .	59
4.4.2 Modeling total costs (CSP) . . . . .	60
4.5 Modeling wind energy generation systems . . . . .	60
4.5.1 Modeling energy flows (wind) . . . . .	60
4.5.2 Modeling total costs (wind) . . . . .	62
4.6 Modeling diesel generator systems . . . . .	62
4.6.1 Modeling energy flows (diesel) . . . . .	62
4.6.2 Modeling total costs (diesel) . . . . .	65
4.7 Modeling desalination systems . . . . .	66
4.7.1 Modeling energy flows (Desal) . . . . .	66
4.7.2 Modeling total costs (Desal) . . . . .	67
4.8 Modeling energy and water storages . . . . .	67
4.8.1 Modeling electricity storage systems (ESS) . . . . .	68
4.8.2 Modeling thermal energy storage systems (TSS) . . . . .	71
4.8.3 Modeling water storage systems (WSS) . . . . .	72

4.9	Limitations of the model . . . . .	72
4.9.1	Time discretization . . . . .	73
4.9.2	Boundaries and mutual exclusivity . . . . .	73
4.9.3	Reduction of computational cost . . . . .	74
4.9.4	Capacity of diesel generators . . . . .	76
<b>5</b>	<b>Case Study: A Cape Verde island</b>	<b>78</b>
5.1	Background of Cape Verde . . . . .	78
5.2	Energy and water demand on Brava . . . . .	80
5.3	Renewable energy potential . . . . .	81
5.4	Input data in the model . . . . .	84
5.4.1	Economic input data . . . . .	84
5.4.2	Input data PV-systems . . . . .	84
5.4.3	Input data CSP . . . . .	85
5.4.4	Input data wind energy converters . . . . .	86
5.4.5	Input data diesel generators . . . . .	87
5.4.6	Input data Electricity Storage Systems . . . . .	88
5.4.7	Input data thermal energy storage systems . . . . .	89
5.4.8	Input data Desalination . . . . .	90
5.4.9	Input data water storage system . . . . .	91
<b>6</b>	<b>Results</b>	<b>92</b>
6.1	Validation of model . . . . .	92
6.2	The optimal energy and water supply system . . . . .	95
6.3	Supply scenarios in comparison . . . . .	96
6.3.1	Integrating renewable energies into the current supply system	96
6.3.2	The optimal desalination process . . . . .	99
6.3.3	Robustness of the optimal desalination system . . . . .	104
6.3.4	Optimal electricity storage system . . . . .	105
6.4	Interference of energy storage systems and desalination processes . . .	107
6.5	Approach and results of a global sensitivity analysis . . . . .	110
6.5.1	Impact of wind velocity and solar irradiation . . . . .	110
6.5.2	Definition of parameters . . . . .	111

6.5.3	Sensitivity of parameters . . . . .	113
6.5.4	Probability of technology implementations . . . . .	116
6.5.5	Impact of sensitive parameters on the energy supply system .	119
6.5.6	Impact of sensitive parameters on the desalination unit . . .	123
6.6	Economic reflection: Investment strategies based on the real option approach (ROA) . . . . .	127
6.7	Global reflection: Concepts for other islands . . . . .	131
<b>7</b>	<b>Conclusions</b>	<b>134</b>
7.1	Summary and conclusions . . . . .	134
7.2	Recommendations for further research . . . . .	138
<b>Bibliography</b>		<b>143</b>
<b>A Model Script</b>		<b>154</b>
<b>B Renewable energy technologies not modeled</b>		<b>185</b>
B.1	Hydro power . . . . .	185
B.2	Ocean powers . . . . .	186
B.3	Geothermal energy . . . . .	188
B.4	Energetic use of biomass . . . . .	189
<b>C Renewable energy powered desalination</b>		<b>192</b>

# List of Figures

2.1	Simple chain from extraction to end-use within an energy supply system	5
2.2	Parabolic Trough (upper left), Linear Fresnel (bottom left), Solar tower (upper right) and Solar Dish (bottom right) [17]	11
2.3	Types of thermal energy storage systems	14
2.4	Ragone Diagram of electrochemical storages	19
2.5	Global stock of water [38]	23
2.6	Overview of desalination methods	24
2.7	Multi-effect distillation process [126]	25
2.8	Humidification-dehumidification process [126]	27
2.9	Membrane distillation process [44]	28
2.10	Mechanical vapour compression process [127]	29
2.11	Reverse osmosis process [127]	29
2.12	Technology combinations RE-powered desalination plants	31
2.13	Concept of Enercon wind-RO system [41]	33
2.14	Development stage and capacity range of the main RE-desalination technologies [46]	34
2.15	SIDS worldwide	35
3.1	Modeling programs for energy systems in comparison	37
3.2	Overview of the optimization approach	41
3.3	Methodology overview	43
3.4	Flow chart of optimization approach	45
3.5	Trajectory example of Morris analysis (left) and relevance of parameters (right)	47
3.6	Binomial pricing tree for two periods: Diesel price development in 20 years	51

4.1 Overview of model . . . . .	53
5.1 The island state Cape Verde . . . . .	79
5.2 Seasonal profile of electricity demand on Brava . . . . .	81
5.3 Solar irradiation in Cape Verde . . . . .	82
5.4 Monthly average of wind speeds on Brava . . . . .	82
5.5 Wind directions in Cape Verde . . . . .	83
5.6 Renewable energy potentials on Brava (top left: pumped hydro, top right: ocean powers, bottom left: geothermal (Fogo), bottom right: precipitation/biomass) [110] . . . . .	83
5.7 Power curve of the Vergnet 275 kW turbine . . . . .	86
5.8 Power curve of the Norwin 225 kW turbine . . . . .	87
5.9 Power curve of the Gyro 10 kW turbine . . . . .	88
5.10 Diesel efficiency curve . . . . .	89
6.1 Desalination potential by excess wind electricity . . . . .	98
6.2 Levelized costs of electricity and water depending on fuel costs . . . . .	102
6.3 Levelised costs of electricity and water . . . . .	103
6.4 Power variations of a variable operating reverse osmosis plant . . . . .	103
6.5 Economic effects of varying energy storage systems . . . . .	105
6.6 Influence of varying storage technologies on the supply system . . . . .	107
6.7 Energy flows of 48 hours depending on ESS . . . . .	108
6.8 Sensitivity of solar irradiation and wind velocity . . . . .	111
6.9 Sample of Morris results . . . . .	115
6.10 Local one-dimensional sensitivity analysis . . . . .	116
6.11 Distributions of the Monte Carlo Analysis . . . . .	117
6.12 Distribution of the energy generation mix . . . . .	118
6.13 Comparative distribution of energy generation technologies . . . . .	120
6.14 Effect of increasing energy consumption and fuel price on the system and electricity costs . . . . .	121
6.15 Renewable energy mix depending on diesel price and variable desalination costs . . . . .	121
6.16 Effects of demand and fuel prices on the energy system . . . . .	122
6.17 Distribution of desalination technologies . . . . .	124

6.18 Selection pattern of desalination process: mechanical vapour compression (MVC) . . . . .	124
6.19 Selection pattern of desalination process: variable reverse osmosis (var-RO) . . . . .	125
6.20 Selection pattern of desalination process: MVC and RO . . . . .	126
6.21 Results of sensitivity analysis considering the diesel price . . . . .	128
6.22 Two-step binomial decision tree of real option approach . . . . .	129
6.23 Comparison of costs without uncertainty with and without future options . . . . .	130
6.24 Result of real option approach for investment strategy . . . . .	131
B.1 Physical correlations in a hydroelectric power station [127] . . . . .	186
B.2 Energy conversion options from biomass [128] . . . . .	189
B.3 Biomass potential on SIDS . . . . .	191
C.1 Possible combinations of renewable energy with desalination technologies [46] . . . . .	192

# List of Tables

2.1	Electricity storage classification by duration . . . . .	16
2.2	Total dissolved solids in waters . . . . .	23
2.3	Islands globally [70] . . . . .	35
3.1	Overview of modeling programs for desalination . . . . .	39
3.2	Analogy between Stock Options and Real Options . . . . .	49
3.3	Option valuation methods . . . . .	50
3.4	Classification and characterization of environmental impacts . . . . .	52
4.1	Optimal supply system - default . . . . .	54
4.2	Hours of autonomy used for electrical energy storage systems . . . . .	75
5.1	Technological data for PV systems . . . . .	85
5.2	Technological data for CSP systems . . . . .	86
5.3	Technological data for wind turbine systems . . . . .	87
5.4	Technological data for diesel generators . . . . .	88
5.5	Technological data for electricity storage systems . . . . .	90
5.6	Technological data for thermal storage systems . . . . .	91
5.7	Technological data for desalination systems . . . . .	91
6.1	Comparison of optimal energy supply system using HOMER and GAMS-model . . . . .	93
6.2	Comparison of optimal energy and water supply system using HOMER and GAMS-model . . . . .	94
6.3	Optimal supply system - default . . . . .	95
6.4	Supply systems of energy scenarios . . . . .	97
6.5	Energy and water balances per year . . . . .	97

6.6	Deviations within the local sensitivity analysis concerning desalination	104
6.7	Input parameters for sensitivity	112
6.8	Output variables for sensitivity	113
6.9	Numerical results of Morris approach	114
6.10	Supply system scenarios for the real option analysis	128
6.11	Properties of other considered islands	132

# List of Acronyms

a-Si	Amorphous silicon thin-film solar cell	
AOSIS	Alliance of Small Island States	
BaU	Business as usual (scenario)	
bin	Binary variable to identify the interpolation range for diesel efficiency linearisation	
c <sub>CO<sub>2</sub></sub>	Specific carbon dioxide emission cost	[€/tCO <sub>2</sub> ]
c <sub>E,O&amp;M</sub>	O&M cost as a specific cost based on the electricity produced	[€/kWh y]
c <sub>fuel</sub>	Specific fuel oil cost based on the energy inside the fuel	[€/kWh <sub>fuel</sub> ]
c <sub>land</sub>	Specific mean land cost	[€/m <sup>2</sup> ]
c <sub>P,O&amp;M</sub>	O&M cost as a specific cost based on the installed power	[€/kW y]
c <sub>plant</sub>	Capacity specific cost of the type of desalination plant	[€/(m <sup>3</sup> /d)]
c <sub>rep,E</sub>	Specific energy replacement cost	[€/kWh] [replacement]
c <sub>rep,P</sub>	Specific power replacement cost	[€/kW] [replacement]
c <sub>Res</sub>	Specific cost of resource consumption and depletion	[€/t]
c <sub>w,O&amp;M</sub>	O&M cost as a specific cost based on the water produced	[€/kWh y]
c <sub>wss</sub>	Specific capacity investment cost	[€/m <sup>3</sup> ]
c <sub>E</sub>	Specific energy investment cost	[€/kWh]
c <sub>P</sub>	Specific power investment cost	[€/kW]
c-Si	multi crystalline solar cells	
CAES	Compressed air energy storage	
Capacity <sub>Desal</sub>	Installed production capacity of desalination plant technology	[m <sup>3</sup> /d]
CdTe	cadmium-telluride thin-film photovoltaic module	
CIS	copper-indium-selenium thin-film photovoltaic module	
CSP	Label of the concentrated solar power subsystem	
d	Set of all days in the time-frame of the model	
DSM	Demand Side Management	
Deration <sub>i</sub>	Losses coefficient of subsystem “i” other then conversion	[-]

Desal	Label of the desalination subsystem	
diesel	Label of the diesel generators subsystem	
DP	Diesel price	
Dump <sub>el</sub>	Flux of electric energy being dumped out of the system	[kWh/h]
Dump <sub>th</sub>	Flux of thermal energy being dumped out of the system	[kWh/h]
E <sub>cons,el</sub>	Electricity consumption of the desalination system to produce desalinated water	[kWh/m <sup>3</sup> ]
E <sub>i,in</sub>	Flux of electric energy entering the technology of subsystem "i"	[kWh/h]
E <sub>i,out</sub>	Flux of electric energy leaving the technology of subsystem "i"	[kWh/h]
E <sub>i</sub>	Installed energy capacity of the technology of subsystem "i"	[kWh/h]
ESS	Label of the electric energy storage subsystem	
$\eta$	Efficiency of conversion or round-trip efficiency	[‐]
$\eta_{el}$	Electrical efficiency of conversion, produced electricity - spent energy ratio	[‐]
$\eta_{th}$	Thermal efficiency of conversion, produced thermal energy - spent energy ratio	[‐]
Exist <sub>i</sub>	Binary variable that allow the size of the system to be either inside the range or zero	
f <sub>O&amp;M</sub>	O&M cost factor as a percentage of the investment cost	[y <sup>-1</sup> ]
FLH	Full load hours	[h/y]
i	Interest rate	[‐]
H2 <sub>PEMFC</sub>	Hydrogen energy storage system with proton exchange membrane (fuel cell)	
H2 <sub>Engine</sub>	Hydrogen energy storage system coupled with combustion engine	
HDH	Humidification-Dehumidification (desalination technology)	
k <sub>CO<sub>2</sub></sub>	Energy specific CO <sub>2</sub> emission from the fuel	[tCO <sub>2</sub> /kWh <sub>fuel</sub> ]
k <sub>LU</sub>	Area coefficient for auxiliary space needed	[‐]
LA	Lead-acid battery	
$\lambda$	Weighting factor of interpolation for diesel efficiency linearisation	[‐]
LCoE	Levelized costs of electricity	[€/kWh]
LCoW	Levelized costs of water	[€/m <sup>3</sup> ]
Li-ion	Lithium-ion battery	
Load	The hourly electric load of the island under exam	[kWh/h]
Losses	The hourly parasitic losses in terms of fraction of the energy stored	[h <sup>-1</sup> ]
LU <sub>i</sub>	Specific land use of the technology of subsystem "i"	[m <sup>2</sup> /kW]

MaxP <sub>i</sub>	Maximum size bound for the technology of subsystem "i"	[kW]
MD	Membrane Distillation (desalination technology)	
MED	Multi-Effect Distillation (desalination technology)	
MVC	Mechanical Vapour Compression (desalination technology)	
MinP <sub>i</sub>	Minimum size bound for the technology of subsystem "i"	[kW]
NaS	Sodium-sulphur battery	
NiCd	Nickel-cadmium battery	
NPC	Net present costs	
ORC	Organic rankine cycle	
p	risk-neutral probability	
P <sub>i</sub>	Installed rated (or peak) power of the technology of subsystem "i"	[kW]
P <sub>W,nom</sub>	Rated power of the standard wind turbine	[kW]
PCM	Phase change materials	
PHS	pumped hydroelectric energy storage system	
pts	Set of all points used in diesel efficiency linearization	
PV	Photovoltaics and label of the photovoltaic subsystem	
r	risk-free rate of return	
RES	Renewable energy sources	
RO	Reverse osmosis (desalination technology)	
ROA	Real option analysis	
SIDS	Small Island Developing States	
$\sigma^2$	standard deviation (in ROA)	
SolarRadiation	Specific incoming solar radiation based on meteorological data	[kW/m <sup>2</sup> ]
SOS	Special order sets (Modeling)	
SpecificOutput	Specific electrical energy output of the standard wind turbine	[kWh/h]
Stored <sub>el</sub>	Amount of electrical energy stored in ess' (that can be totally released)	[kWh]
Stored <sub>th</sub>	Amount of thermal energy stored in tss' (that can be totally released)	[kWh]
t	Set of all hours in the time-frame of the model	
TC <sub>i</sub>	Total cost of the technology of subsystem "i"	[€]
Th <sub>i,in</sub>	Flux of thermal energy entering the technology of subsystem "i"	[kWh/h]
Th <sub>i,out</sub>	Flux of thermal energy leaving the technology of subsystem "i"	[kWh/h]
TSS	Label of the thermal energy storage subsystem	
V <sub>wss</sub>	Installed storage capacity of the water storage	[m <sup>3</sup> ]
V <sub>cut-in</sub>	wind velocities, here cut-in	[m/s]
V-redox	Vanadium-redox-flow battery	

var-RO	variable reverse osmosis (desalination technology)
W	Label of the wind turbine subsystem
Water <sub>reserve</sub>	The amount of water stored in the water storage [m <sup>3</sup> ] system
WaterDemand	The daily water demand of the island under exam [m <sup>3</sup> /d]
WaterGen <sub>Desal</sub>	hourly water output of the desalination system [m <sup>3</sup> /d]
WEC	Wind energy converter
Wind1	scenario with small wind capacity
Wind2	scenario with large wind capacity
Wind1+PV	scenario with small wind capacity und PV systems
WSS	Label of the water storage subsystem
y	year
ZnBr	zinc-bromine flow battery
$\xi$	Binary variable used to trigger the mutual exclusivity of some model variables