



Bernd Engel (Herausgeber)

Development of a Process for Integrated Development and Evaluation of Energy Scenarios for Lower Saxony

Final report of the research project NEDS – Nachhaltige
Energieversorgung Niedersachsen

Schriftenreihe des Energie-Forschungszentrums Niedersachsen

efzn

Energie-Forschungszentrum
Niedersachsen

Development of a Process for Integrated Development and Evaluation of Energy Scenarios for Lower Saxony

Final report of the research project NEDS –
Nachhaltige Energieversorgung Niedersachsen

April 1, 2015 – July 31, 2019

Band 61



Cuvillier Verlag Göttingen

<https://cuvillier.de/de/shop/publications/8139>

Copyright:
Cuvillier Verlag, Inhaberin Annette Jentzsch-Cuvillier, Nonnenstieg 8, 37075 Göttingen,
Germany

Telefon: +49 (0)551 54724-0, E-Mail: info@cuvillier.de, Website: <https://cuvillier.de>



Table of Contents

1. Introduction.....	1
2. State of the Art Regarding Energy Scenarios for Lower Saxony	4
3. Project Framework.....	9
3.1 Project Targets	9
3.2 System Boundary.....	10
4. Development of a Methodology for the Sustainability Evaluation of Energy Scenarios	13
4.1 Process for Integrated Development and Evaluation of Energy Scenarios (PDES).....	14
4.2 Information Model.....	16
5. Sustainability as Evaluation Concept	21
5.1 Empirical Analyses of Evaluation Criteria for a Sustainable Energy System and the Importance of Sustainability Dimensions	23
5.2 Synthesis of Evaluation Criteria.....	34
6. Development of Future Scenarios	36
6.1 Scenario Planning.....	36
6.1.1 Scenario Preparation.....	37
6.1.2 Scenario-Field Analysis.....	38
6.1.3 Scenario Prognostic	40
6.1.4 Scenario Development	42
6.2 Description of Future Scenarios	42
7. Diffusion and Adoption of Innovations for the Energy Transition.....	46
7.1 Theoretical Grounding of the Diffusion of Innovations.....	47
7.2 Selection of Innovations	48
7.3 Research Design.....	51
7.4 Diffusion Profiles	52
7.4.1 Photovoltaic with Energy Storage.....	53
7.4.2 Smart Meter.....	62
7.4.3 Dynamic Electricity Tariffs.....	64
7.4.4 Heat Pumps	67
7.4.5 Electric Mobility and Charging Infrastructure	70
7.5 Discussion.....	72
7.5.1 Practical Implications	73
7.5.2 Reflection and Future Research.....	74



8.	From Story to Simulation	78
8.1	Definition and Quantification of Attributes.....	79
8.2	Development of Alternatives	83
8.3	Transition Paths	86
8.4	Selecting Future Scenarios for Simulation	89
9.	Modeling and Simulation	90
9.1	Theoretical and Empirical Analysis of User-Behavior	92
9.1.1	Description of User Behavior.....	93
9.1.2	Interpreting Differences between Activity Patterns as Caused by Contextual Factors	98
9.1.3	Estimation of Behavioral Adaptive Costs	99
9.2	Building Model	108
9.2.1	Simulation Environment	108
9.2.2	Appliance.....	109
9.2.3	User.....	111
9.2.4	Power Flexibility.....	119
9.2.5	Control Systems.....	122
9.2.6	Forecasting Methods	124
9.2.7	Economic Analysis	124
9.3	Smart Grid Model	125
9.3.1	Load Management of Smart Buildings.....	125
9.3.2	Multi-Agent System ISAAC.....	126
9.3.3	Flexibility in ISAAC	127
9.3.4	Optimization Goals.....	129
9.4	Coupling of Building and Smart Grid Model	132
9.5	Simulation Scenario and Execution on the Micro-Level	133
9.6	The Integrated Grid and Market Model	137
9.6.1	Grid Topology, Power System Delimitation, Interfaces and Degree of Freedom.....	137
9.6.2	Method of the Integrated Grid and Market Model	139
9.6.3	Structure and Content of the Used Database	139
9.6.4	Market Simulation	141
9.6.5	Grid Simulation.....	142
9.6.6	Application of the Integrated Grid and Market Model to NEDS.....	142



9.7	Optimized Distribution Grid Planning	143
9.7.1	Grid Topology, Power System Delimitation, Interfaces and Degree of Freedom.....	144
9.7.2	Method of the Grid-Planning Algorithm.....	146
9.7.3	Structure and Content of the Used Database	147
9.7.4	Mathematical Description of the Grid Topology.....	148
9.7.5	Topology Optimization Module	149
9.7.6	The Grid Reinforcement Module	152
9.7.7	Application of the Grid-Planning Algorithm to NEDS	158
9.8	Computable General Equilibrium Model.....	160
9.9	Life-Cycle Assessment for the Derivation of Environmental and Social Preference Scores.....	164
9.10	Coupling of Models on Macro-Level.....	168
10.	Results of the Energy System Models	169
10.1	Smart Grid Model	169
10.2	Results of the Integrated Grid and Market Model.....	175
10.3	Results of the Grid Planning Algorithm.....	177
10.4	Macroeconomic Developments under Different Energy Policies.....	181
10.5	Life-Cycle Assessment.....	190
11.	Evaluation of Transition Paths.....	194
11.1	PROMETHEE.....	195
11.2	Multi-Period PROMETHEE (MP-PROMETHEE).....	196
11.3	Results.....	201
11.4	Discussion.....	205
12.	Conclusion.....	207
13.	Acknowledgments.....	213
14.	References.....	214
15.	List of Figures.....	233
16.	List of Tables	237
17.	Acronyms.....	239
18.	Appendix	241