Renewable Energies in Germany’s Electricity Market
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A Biography of the Innovation Process

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Springer
Translated and updated version of:

The book is based on the research project “Innovationsbiographien der erneuerbaren Energien”, FKZ 0327607, funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

DOI 10.1007/978-90-481-9905-1
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2010937995

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Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)
Several people have contributed to this research project in one way or the other. First, the authors wish to acknowledge the financial support provided by the Federal Ministry of Environment for funding the research project. Our special appreciation goes to Reinhart Kaiser, Dr. Wolfhart Dürrschmidt and Gisela Zimmermann from the Renewable Energy Department of the Federal Ministry of Environment, who encouraged the research team and shared their experiences in the field of governing innovation processes. While we are grateful for their attendance to our research with constructive criticism and support, they stay blameless for any errors that remain.

During the course of the project many people contributed to the research by giving us interviews. We would like to thank all our interview partners for providing detailed and precious information, for helpful comments and for sharing their insights in this comprehensive field of innovation.

In particular we would like to thank the junior members of the research staff, Matthias Futterlieb and Johanna Kösters for their reliable and qualified assistance and their pleasant way of cooperating. Also those who helped us to transform the research report into English deserve special words of gratitude: the translator Fiona Skubella for her thorough work, Manolita Wiehl for profound editorial amendments and Kris Freeman for going through the introduction chapter.

Finally, we wish to take this opportunity to thank our colleagues at the Berlin Technical University and the Federal Ministry of Environment for sharing their resources and data, for comments on presentations of our research, for offering a pleasant and interesting environment and technical support. We particularly thank Susanne Schön and Heike Walk for providing inspiration and encouragement.
Contents

1 Introduction .................................................................................................................. 1

2 Introduction to the Methodology ................................................................................. 7
  2.1 Research Questions and Objectives ................................................................. 7
  2.2 Procedure ........................................................................................................... 8
    2.2.1 A Note on Style......................................................................................... 9
  2.3 Methodology Used in the Constellation Analysis .............................................. 9
    2.3.1 Constellation Analysis ........................................................................... 9
    2.3.2 Constellation Elements ......................................................................... 10
    2.3.3 Relations ............................................................................................... 10
    2.3.4 Context ................................................................................................... 11
    2.3.5 The Concept of a Biography of Innovation ............................................ 11
  2.4 Governing Political and Social Processes .......................................................... 12

References ...................................................................................................................... 13

3 Cross-sectoral Interventions, Events and Processes .................................................... 15
  3.1 Crises as Triggers for Social Rethinking Processes .......................................... 15
    3.1.1 Environmental and Climate Crises ....................................................... 16
    3.1.2 Oil Price Crises ..................................................................................... 18
    3.1.3 Nuclear Energy Crisis .......................................................................... 19
    3.1.4 Energy Supply Crises and Electricity Gap Debate ................................ 20
    3.1.5 Food Crisis ............................................................................................ 22
  3.2 International Climate Protection Research and Politics .................................... 22
    3.2.1 International Climate Protection Process ............................................. 23
    3.2.2 Establishment of the International Renewable Energy Agency (IRENA) .... 31
  3.3 Incentives for Energy Policy at EU level .......................................................... 32
    3.3.1 Liberalization of the Energy Markets .................................................... 33
    3.3.2 Renewables and Climate Protection Policy at EU Level ....................... 35
    3.3.3 European Emissions Trading (Cap and Trade) ...................................... 40
  3.4 Emergence of National Problem Awareness and Process of Institutionalization ...................................................................................................................... 41
    3.4.1 Institutionalization of Environmental Protection .................................. 42
3.4.2 Climate Protection in Politics and Administration .................. 42
3.4.3 Institutionalization of Renewable Energy Policy ...................... 46
3.4.4 Establishment of Associations .................................................. 47

3.5 Energy and Climate Policy Strategies and Objectives
at National Level .............................................................................. 49
3.5.1 Guidelines on Energy Policy Issued
by the Federal Government in 1991 .............................................. 49
3.5.2 Change of Government to Red-Green in 1998 ......................... 49
3.5.3 National Climate Protection Programs ..................................... 49
3.5.4 Nuclear Phaseout Resolution of 2001 ........................................ 50
3.5.5 Sustainability Strategy 2002 .................................................... 51

3.6 Government Aid for Renewable Energy ...................................... 51
3.6.1 Market Incentive Program ....................................................... 52
3.6.2 Federal Research Funding ....................................................... 52
3.6.3 Funding on State Level ............................................................ 57

3.7 StrEG and EEG as Key Policy Measures .................................... 57
3.7.1 The Electricity Feed-In Act (StrEG) ....................................... 58
3.7.2 The Renewable Energy Sources Act (EEG) .......................... 61
3.7.3 Integrated Energy and Climate Program
of the Federal Government .......................................................... 64

3.8 Environmental and Planning Law for Renewable
Energy Projects .................................................................................. 66
3.8.1 Amendment of Regional Planning Law .................................. 66
3.8.2 Zoning Law/Planning Permission Law ................................. 67
3.8.3 Legal Basis for Grid Connection and Grid Expansion ............ 69

3.9 Overall Parameters of the Electricity Sector ............................... 70
3.9.1 Integration of the Electricity Industry
in Europe – Actors and Influencing Factors ............................... 70
3.9.2 Structure of the German Electricity Supply Sector .................. 72
3.9.3 Liberalization of the Energy Market – The German
Energy Industry Act ................................................................. 73
3.9.4 Current Courses Set in the Energy Sector ............................... 76

References ............................................................................................ 80

4 Innovation Framework for Generating Biogas
and Electricity from Biogas ................................................................. 89
4.1 Preliminary Remarks .................................................................... 90
4.2 Phase-Based Analysis of the Innovation Process ....................... 90
4.2.1 Historical Retrospective ....................................................... 90
4.2.2 Phase 1: Pioneering Phase, 1970–1990 ................................. 91
4.2.3 Phase 2: First Phase of Emergence From
1990 to 1999 .............................................................................. 100
4.2.4 Phase 3: Intensified Emergence Between 2000
and Mid-2004 ............................................................................ 110
4.2.5 Phase 4: Take-off from Mid-2004 to the End of 2006 ......... 121
4.2.6 Phase 5: Setback in Development 2007/2008 ................. 138
4.2.7 Consolidation from Mid-2008 Onward and Future Prospects .............................................................. 148
References ................................................................................................... 155

5 Innovation Conditions in the Case of Solar Power Generation .............................................................. 161
5.1 Preliminary Remarks .............................................................................................................................. 161
5.2 Phase-Specific Analysis of the Innovation Process .............................................................................. 162
5.2.1 A Historical Overview .......................................................................................................................... 162
5.2.2 Phase 1: Pioneering Phase, 1970–1985 ............................................................................................... 163
5.2.3 Phase 2: Stagnation of Industry Engagement, R&D, 1986–1991 ......................................................... 168
5.2.4 Phase 3: Large-scale Testing from 1991 to 1994 ............................................................................. 178
5.2.5 Phase 4: Uncertainty and Slowdown, 1994–1998 ........................................................................... 184
5.2.6 Phase 5: Breakthrough, 1999–2003 .................................................................................................... 193
5.2.7 Phase 6: Development Boom from 2004 ....................................................................................... 206
References ................................................................................................... 224

6 Conditions for Innovation in Geothermal Power Generation .............................................................. 229
6.1 Preliminary Remarks .............................................................................................................................. 229
6.2 Phase-specific Analysis of the Innovation Process .............................................................................. 232
6.2.1 Use of Geothermal Heat in the Former GDR ..................................................................................... 232
6.2.2 Phase 1: 1985–2003, Research and Development, Preliminary Projects to Generate Electricity .... 233
6.2.3 Phase 2: Formation of Prospective Structures from 2004 ................................................................ 241
6.2.4 Outlook ........................................................................................................................................... 257
References ................................................................................................... 259

7 Innovation Framework for Generating Electricity from Wind Power .................................................... 261
7.1 Preliminary Remarks .............................................................................................................................. 261
7.2 Phase-Based Analysis of the Innovation Process .............................................................................. 262
7.2.1 Phase 1: Pioneering Phase – Mid-1970s Until 1986 .......................................................................... 263
7.2.3 Phase 3: Breakthrough 1991–1995 .................................................................................................... 273
7.2.4 Phase 4: Development Dip in the Mid-1990s ................................................................................... 283
7.2.5 Phase 5: Wind Power Boom and Reorganization 1997/98 to 2002 ........................................ 289
7.2.6 Phase 6: Consolidation and Divergence of the Pathway from 2002 Onward ............................ 298
References ................................................................................................... 326
8 Innovation Framework for Generating Electricity from Hydropower ................................................................. 333
  8.1 Preliminary Remarks .............................................................................................................................. 333
  8.2 Hydropower in the Pioneering Phase (Before 1930) ........................................................................... 334
    8.2.1 Turbine Technology ..................................................................................................................... 335
    8.2.2 Hydropower Plants ....................................................................................................................... 337
  8.3 Phase-Based Analysis of the Course of Innovation .............................................................................. 337
    8.3.1 Phase 1: Hydropower Maturation Phase (1930–1990) ................................................................. 337
    8.3.2 Phase 2: Revitalization of Small Hydropower, 1990–1999 ............................................................. 347
    8.3.3 Phase 3: Modernization Under Environmental Constraints, 2000 to the Present ..................... 354
    8.3.4 Prospects ...................................................................................................................................... 363
References ...................................................................................................................................................... 364

9 Cross-Sectional Comparison ..................................................................................................................... 367
  9.1 Key Driving Forces in the Innovation Biographies .............................................................................. 368
    9.1.1 Civic Activities, Creative Environment and Pioneers ............................................................... 368
    9.1.2 Advocacy Coalitions .................................................................................................................... 369
    9.1.3 Political Window .......................................................................................................................... 371
    9.1.4 Political Strategies and Lead Principles .................................................................................... 371
    9.1.5 Institutionalization and Market Incentives ............................................................................... 372
    9.1.6 Multi-Level Policy as the Driver .............................................................................................. 375
    9.1.7 Technology-Bound Driving Forces ........................................................................................... 376
  9.2 Inhibitory Influences in the Innovation Biographies ............................................................................ 378
    9.2.1 Investment Costs and Limited Resources .................................................................................. 378
    9.2.2 Inhibitory Advocacy Coalitions .................................................................................................. 378
    9.2.3 Insufficient and Incompatible Infrastructure ............................................................................. 379
    9.2.4 Loss of Acceptance ..................................................................................................................... 380
  9.3 Comparison of Innovation Processes: Characteristic Phases and Different Processes ...................... 381
    9.3.1 Pioneering Phase or Early Phase Including Pilot Applications .................................................. 382
    9.3.2 Inception .................................................................................................................................. 383
    9.3.3 Breakthrough .............................................................................................................................. 383
    9.3.4 Expansion and Boom Phases ..................................................................................................... 384
    9.3.5 Phases of Instability and Crisis .................................................................................................. 385
    9.3.6 Phases of Stabilization and Consolidation ............................................................................... 386

10 Insights into the Drivers of Innovation .................................................................................................. 387
  10.1 Phase-Specific Adjustment of Policies .............................................................................................. 388
    10.1.1 Identifying and Strengthening Innovation Processes in the Early Phase ................................. 388
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1.2 On the Path to a Breakthrough – Stimulating the Process in its Inception Phase</td>
<td>390</td>
</tr>
<tr>
<td>10.1.3 In the Expansion Phase: Easing Integration into the System and Avoiding Acceptance Problems</td>
<td>390</td>
</tr>
<tr>
<td>10.1.4 Sustaining Innovation Processes by Corrective Controls</td>
<td>392</td>
</tr>
<tr>
<td>10.1.5 Driving Innovation During Unstable Phases</td>
<td>392</td>
</tr>
<tr>
<td>10.2 Recognizing and Limiting Unintended Outcomes in a Timely Manner</td>
<td>394</td>
</tr>
<tr>
<td>10.3 Integrating Levels of Action and Actors</td>
<td>395</td>
</tr>
<tr>
<td>10.3.1 Coordination and Integration of Policy Levels</td>
<td>395</td>
</tr>
<tr>
<td>10.3.2 Integrating the Goals of Government Portfolios</td>
<td>396</td>
</tr>
<tr>
<td>10.3.3 Integrating Sub-Constellations</td>
<td>396</td>
</tr>
<tr>
<td>10.3.4 Planning Policies</td>
<td>396</td>
</tr>
<tr>
<td>10.4 Synchronization-Based Policy</td>
<td>397</td>
</tr>
<tr>
<td>10.4.1 Temporal Synchronization</td>
<td>397</td>
</tr>
<tr>
<td>10.4.2 Accumulation of Policy Action</td>
<td>397</td>
</tr>
<tr>
<td>10.4.3 Synchronizing Heterogeneous Innovation Processes</td>
<td>398</td>
</tr>
<tr>
<td>10.5 Coherent Policies in Complex Constellations</td>
<td>398</td>
</tr>
<tr>
<td>10.6 Future Challenges Facing Governance</td>
<td>399</td>
</tr>
<tr>
<td>10.6.1 From Integration to Transformation in the Electricity Sector – a Complex Policy Task</td>
<td>399</td>
</tr>
<tr>
<td>10.6.2 Compatibility of Power Generation Systems</td>
<td>399</td>
</tr>
<tr>
<td>10.6.3 Optimizing the Power Line Infrastructure</td>
<td>400</td>
</tr>
<tr>
<td>10.6.4 Prospects for System Transformation in the Electricity Sector</td>
<td>401</td>
</tr>
<tr>
<td>Authors’ Biographies</td>
<td>403</td>
</tr>
<tr>
<td>Annex</td>
<td>405</td>
</tr>
<tr>
<td>Index of Legal Sources</td>
<td>405</td>
</tr>
<tr>
<td>Energy Law</td>
<td>405</td>
</tr>
<tr>
<td>Environmental and Building Law</td>
<td>406</td>
</tr>
<tr>
<td>EU Directives and Court Rulings</td>
<td>407</td>
</tr>
</tbody>
</table>
List of Figures

Fig. 2.1  Constellation elements (acc. to Schön et al. 2007) ........................................ 10
Fig. 2.2  Relations (acc. to Schön et al. 2007) ................................................................. 11

Fig. 4.1  Phases of the development of biogas use in Germany ........................................ 90
Fig. 4.2  Constellation phase 1: pioneering phase 1970–1990 ............................................ 92
Fig. 4.3  Constellation phase 2: first phase of emergence between 1990 and 1999 ............ 101
Fig. 4.4  Total capacity and plant numbers of biogas utilization in Germany until 1999 ......... 106
Fig. 4.5  Constellation phase 3: intensified emergence between 2000 and mid-2004 .......... 111
Fig. 4.6  Total capacity and plant numbers of biogas utilization in Germany until 2004 ......... 116
Fig. 4.7  Constellation Phase 4: take-off between mid-2004 and 2006 .............................. 121
Fig. 4.8  The increase in the area of land in Germany used for cultivating renewable resources .................................................................................................................. 124
Fig. 4.9  Area under corn cultivation in thousands of hectare as of May 2009 (Dt. Maiskomitee; authors illustration) ................................................................. 136
Fig. 4.10 Constellation phase 5: setback in development 2007/2008 ................................. 139
Fig. 4.11 Total capacity and number of plants utilizing biogas in Germany up to 2008 .......... 144

Fig. 5.1  Phases of the development of photovoltaics in Germany ...................................... 162
Fig. 5.2  Constellation phase 1: pioneering phase, 1970–1985 ........................................... 164
Fig. 5.3  Federal project grants for photovoltaics since 1974 (BMU 2009a, 16) ..................... 165
Fig. 5.4  Constellation phase 2: stagnation of industrial engagement, R&D, 1986–1991 ......... 169
Fig. 5.5  Industry development of thin-film solar cells (Prognos et al. 2007b, 410) .................. 174
Fig. 5.6  Constellation phase 3: Large-scale testing from 1991 to 1994 ............................. 178
Fig. 5.7  Constellation phase 4: uncertainty and slowdown from 1994 to 1998 .................... 185
Fig. 5.8 Constellation phase 5: breakthrough, 1999–2003 ......................... 194
Fig. 5.9 Developments of selected companies in the field of silicon solar cells from 1990 to 2006 (author’s own diagram based on information from Prognos et al. 2007b, 408)................................. 203
Fig. 5.10 Constellation phase 6: development boom, from 2004 .......... 206
Fig. 5.11 Developments in the price of turnkey photovoltaic rooftop systems of between 2 and 5 kW (Oppermann 2004, 48; Photon (several issues); IfnE calculations)............................... 214
Fig. 5.12 Annual expansion of installed capacity compared with cell production in Germany (BSW 2009; BMU 2007; author’s own diagram)................................................................. 216

Fig. 6.1 Development phases of geothermal power generation in Germany............................................................. 231
Fig. 6.2 Constellation phase 1: Research and development phase, 1985–2003................................................................. 233
Fig. 6.3 Federal project funding for renewable energy since 1974 BMU 2009b, 42) ................................................................. 235
Fig. 6.4 Constellation phase 2: Formation of prospective structures from 2004................................................................. 242

Fig. 7.1 Phases of the development of wind power use in Germany........ 262
Fig. 7.2 Constellation phase 1: pioneering phase – mid-1970s until 1986 .............................................................................. 263
Fig. 7.3 Constellation phase 2: inception – changes in the context of energy policy between 1986 and 1990................................. 268
Fig. 7.4 Constellation phase 3: breakthrough 1991 to 1995 ................ 274
Fig. 7.5 Constellation phase 4: development dip in the mid-1990s ...... 284
Fig. 7.6 Constellation phase 5: wind power boom and reorganization 1997/98 to 2002.................................................................. 290
Fig. 7.7 Constellation phase 6: consolidation and divergence of the development trajectory from 2002 ......................................... 298
Fig. 7.8 Number of wind turbines in Germany, cumulative and annual expansion (BWE 2009)......................................................... 302
Fig. 7.9 Predicted German power generation from wind until 2020 ...... 325

Fig. 8.1 Phases of the development of hydropower use in Germany...... 334
Fig. 8.2 Constellation of Phase 1: Maturation phase 1930–1990........ 338
Fig. 8.3 Constellation of Phase 2: Revitalization of small hydropower 1990–1999................................................................. 347
Fig. 8.4 Constellation of Phase 3: Modernization under environmental constraints ................................................................. 355

Fig. 9.1 Phases in the innovation process of renewable energies .......... 382
Fig. 9.2 Key to phase types................................................................. 382
List of Tables

Table 3.1  Key milestones in the international climate protection process (Coenen 1997, 162; supplemented) ........................................... 31
Table 4.1  Remuneration for electricity derived from biogas according to § 8 EEG 2000 ................................................................. 114
Table 4.2  Tariffs for electricity produced from biogas according to § 8 EEG 2004 (cents/kWh) .......................................................... 126
Table 4.3  Tariffs for electricity and gas according to § 27 and Annex 2 EEG 2009 (Cent/kWh) ............................................................. 150
Table 5.1  Photovoltaics: installed capacity in Germany from 1990 to 1994 (BMU 2009b) ................................................................. 182
Table 5.2  Photovoltaics: installed capacity in Germany from 1990 to 1998 (BMU 2009b) ................................................................. 188
Table 5.3  Minimum compensation payment for solar electricity in StrEG and EEG 2000 ................................................................. 198
Table 5.4  Development of costs for systems of 3–4 kW (in EUR/kW) (as per Oppermann 2004, 48) ....................................................... 201
Table 5.5  Development of costs for systems of up to 10 kW (in EUR/kW) according to component over the course of the 100,000 Roofs Program (as per Oppermann 2004, 48) ........................................ 202
Table 5.6  Photovoltaics: installed capacity in Germany, 1990–2003 (BMU 2009b) ................................................................. 202
Table 5.7  Compensation for PV rooftop systems up to 30 kW as stipulated in the StrEG and the EEG ............................................ 208
Table 5.8  Photovoltaics: installed capacity in Germany, 1990–2008 (BMU 2009b) ................................................................. 209
Table 5.9  Thin cell production in Germany 2007/2008 ..................... 219
Table 6.1  EEG 2004/2009 compensation rates for geothermal energy ................................................................. 244
Table 6.2  Geothermal power generation in Germany (or projects with German participation) ................................................................. 250
Table 7.1  Development of turbine numbers and installed capacity in Germany 1991–1995 (Molly 2009, 9) .............................................................. 279
Table 7.2  Development of numbers in wind turbines and installed capacity in Germany 1994–1998 (Molly 2009, 9) ........................................... 286
Table 7.3  Development of turbine numbers and installed capacity in Germany 1997–2002 (Molly 2009, 9) .............................................................. 294
Table 7.4  Overview of approved offshore wind farm projects in the EEZ as of November 2009 ............................................................................ 316
Table 7.5  Approved grid connections in the North Sea, as of November 2009 ......................................................................................... 318
Table 8.1  Installed capacity at small hydropower plants, 1988–1994 ....... 343
Table 8.2  Compensation rules under StrEG 1991–1998 ....................... 350
Table 8.3  Installed capacity and generation of electricity from hydropower, 1990–1999 ................................................................. 352
Table 8.4  Overview of compensation rates for hydropower under EEG 2000, 2004 and 2009 ................................................................. 358
Abbreviations

AG        Aktiengesellschaft
ARGE      Arbeitsgemeinschaft
AWD       Arbeitsgemeinschaft Wasserkraftwerke Deutschland
BauGB     Baugesetzbuch
BDEW      Bundesverband der Energie- und Wasserwirtschaft
BDW       Bund Deutscher Wasserkraftwerke
BEE       Bundesverband Erneuerbare Energie
BImSchG   Bundesimmissionsschutzgesetz
BLS       Bundesverband Landschaftsschutz
BMBF      Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie
BMFT      Bundesministerium für Forschung und Technologie (later the BMBF)
BMU       Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
BMVBW     Bundesministerium für Verkehr, Bau- und Wohnungswesen
BMW 5     Bundesministerium für Wirtschaft und Arbeit (from 2002 till 2005)
BMW 6      Bundesministerium für Wirtschaft und Technologie (since 2005)
BNSchG     Bundesnaturschutzgesetz
BSH       Bundesamt für Seeschifffahrt und Hydrographie
BT-Drs     Bundestagsdrucksache
BTO Elt    Bundestarifordnung Elektrizität
BUND      Bund für Umwelt und Naturschutz Deutschland
BWE       Bundesverband Windenergie
CCS       Carbon Capture and Storage
CdTe      Cadmium Telluride
CDU       Christlich Demokratische Union
CHP       Combined Heat and Power
CIGS      Copper Indium Gallium Diselenide
CIGSSe    Copper-Indium-Gallium-Sulfur
CIS       Copper Indium Diselenide
CO₂       Carbon dioxide
CSU       Christlich Soziale Union
DASA      Deutsche Aerospace Aktiengesellschaft, today: Daimler Chrysler Aerospace AG
<table>
<thead>
<tr>
<th>Abbreviation</th>
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</tr>
</thead>
<tbody>
<tr>
<td>DBU</td>
<td>Deutsche Bundesstiftung Umwelt</td>
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<tr>
<td>dena</td>
<td>Deutsche Energie-Agentur</td>
</tr>
<tr>
<td>DEWI</td>
<td>Deutsches Windenergie-Institut</td>
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<td>DFS</td>
<td>Deutscher Fachverband Solarenergie e.V.</td>
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<td>DFVLR</td>
<td>Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt</td>
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<td>DGS</td>
<td>Deutsche Gesellschaft für Sonnenenergie</td>
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<td>DGW</td>
<td>Deutsche Gesellschaft für Windenergie</td>
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<td>DIW</td>
<td>Deutsches Institut für Wirtschaftsforschung</td>
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<td>DLR</td>
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<td>DNR</td>
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<td>DPG</td>
<td>Deutsche Physikalische Gesellschaft</td>
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<td>DtA</td>
<td>Deutsche Ausgleichsbank</td>
</tr>
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<td>EEG</td>
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<td>EFG</td>
<td>Edge-defined Film-fed Growth</td>
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<td>EFP</td>
<td>Energieforschungsprogramm</td>
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<td>EGs</td>
<td>Enhanced Geothermal System</td>
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<td>EnBW</td>
<td>Energie Baden-Württemberg AG (utility)</td>
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<td>EuGH</td>
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<td>EWG</td>
<td>Europäische Wirtschaftsgemeinschaft</td>
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<td>FAL</td>
<td>Bundesforschungsanstalt für Landwirtschaft, Braunschweig</td>
</tr>
<tr>
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<td>Freie Demokratische Partei</td>
</tr>
<tr>
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<td>Flora-Fauna-Habitat</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
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<td>ForschungsVerbund Sonnenenergie</td>
</tr>
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<td>Größter Anzunehmender Unfall</td>
</tr>
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<td>GbR</td>
<td>Gesellschaft bürgerlichen Rechts</td>
</tr>
<tr>
<td>GDR</td>
<td>German Democratic Republic</td>
</tr>
<tr>
<td>GFZ</td>
<td>GeoForschungsZentrum Potsdam</td>
</tr>
<tr>
<td>GGA</td>
<td>Institut für Geowissenschaftliche Gemeinschaftsaufgaben</td>
</tr>
<tr>
<td>GmbH</td>
<td>Gesellschaft mit beschränkter Haftung</td>
</tr>
<tr>
<td>GROWIAN</td>
<td>Großwindanlage</td>
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<td>GT</td>
<td>Geothermie</td>
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<tr>
<td>GTN</td>
<td>Geothermie Neubrandenburg GmbH</td>
</tr>
<tr>
<td>GtV</td>
<td>Geothermische Vereinigung</td>
</tr>
<tr>
<td>GtV-BV</td>
<td>Geothermische Vereinigung – Bundesverband Geothermie e.V.</td>
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<tr>
<td>GWh</td>
<td>Gigawatt per hour</td>
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<tr>
<td>HDR</td>
<td>Hot Dry Rock</td>
</tr>
<tr>
<td>HFG</td>
<td>Helmholtz-Gemeinschaft deutscher Forschungszentren</td>
</tr>
<tr>
<td>HFR</td>
<td>Hot Fractured Rock</td>
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<tr>
<td>HVDC</td>
<td>High Voltage Direct Current</td>
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HMI  Hahn-Meitner-Institute Berlin, now: Helmholtz-Zentrum Berlin
IBP  Fraunhofer Institut für Bauphysik
IEA  International Energy Agency
IEKP  Integriertes Energie- und Klimaprogramm
IFEU  Institut für Energie- und Umweltforschung
IPCC  Intergovernmental Panel on Climate Change
ISE  Fraunhofer Institut für Solare Energiesysteme
ISES  International Solar Energy Society
ISET  Institut für Solare Energieversorgungstechnik e. V.
ISFH  Institut für Solarenergieforschung Hameln
ISI  Fraunhofer Institut für System- und Innovationsforschung
ISUSI  Institute for Sustainable Solutions and Innovations
KFA  Kernforschungsanstalt
KfW  Kreditanstalt für Wiederaufbau
KTBL  Kuratorium für Technik und Bauwesen in der Landwirtschaft
kW  Kilowatt
kWh  Kilowatt per hour
MAP  Marktanreizprogramm
MBB  Messerschmidt Bölkow Blohm (manufacturing company)
MW  Megawatt
MW\text{el}  Megawatt, electric capacity
MW\text{h}  Megawatt per hour
MW\text{p}  Megawatt, peak
MW\text{th}  Megawatt, thermal capacity
NABU  Naturschutzbund Deutschland e. V.
NGO  Non governmental organization
NRW  Nordrhein-Westfalen
OECD  Organization for Economic Co-operation and Development
OPEC  Organization of the Petroleum Exporting Countries
ORC  Organic Rankine Cycle
PR  Performance Ratio
PTJ  Projektträger Jülich
PV  Photovoltaics
PVD  Physical Vapor Deposition
REN  Rationelle Energieverwendung und Nutzung
RL  Richtlinie
SDLWindV  Verordnung zu Systemdienstleistungen durch Windenergieanlagen
SEA  Strategic Environmental Assessment
SFV  Solarenergie-Förderverein Deutschland e. V.
sm  Seamile (1852 m)
SPD  Sozialdemokratische Partei Deutschlands
SRU  Sachverständigenrat für Umweltfragen
StrEG  Stromeinspeisungsgesetz
TAB  Büro für Technikfolgenabschätzung beim Deutschen Bundestag
TEC  Treaty establishing the European Community
TU  Technische Universität
UMTS  Universal Mobile Telecommunications System
UN  United Nations
UNEP  United Nations Environment Program
UNFCCC  United Nations Framework Convention on Climate Change
VDEW  Verband der Elektrizitätswirtschaft
VDMA  Verband Deutscher Maschinen- und Anlagenbau
VSI  Verband mittelständischer Solarindustrie e.V.
VZBV  Verbraucherzentrale Bundesverband
WFD  EU Water Framework Directive
WMEP  Wissenschaftliches Mess- und Evaluierungsprogramm
WMO  World Meteorological Organisation
ZAE  Zentrum für Angewandte Energieforschung
ZGI  Zentrales Geologisches Institut
ZIP  Zukunftsinvestitionsprogramm
ZIPE  Zentralinstitut für Physik der Erde
ZSW  Zentrum für Sonnenenergie- und Wasserstoff-Forschung
Breathtaking international decarbonization pathways, the proposal of a European supergrid or the ambitious solar project in the North African desert may be key features of future roadmaps toward a zero-carbon power sector. But it is safe to say that the primary function of the deployment of renewable energy today is the establishment of a pivotal landmark for a process of transition to sustainable energy and for a policy of climate change mitigation. At the same time, continuing growth in the renewable energy sector clearly triggers innovations and the diffusion of relevant technologies.

Although Germany’s hydropower resources are limited, the country has been an influential forerunner in the deployment of renewable energies on a national scale, primarily through the use of wind, solar and biomass energies. Rising revenues and a growing workforce also reflect the growth rates we have seen in electricity generation from renewable energies in Germany over a period of 20 years, rates that would once have been considered impossible. While Germany’s gross domestic product fell by about 5% in 2009 due to the worldwide economic crisis, revenues in the renewable energy sector saw a 10% gain that was triggered by domestic as well as international demand.

Funded by the German Federal Ministry of the Environment, the applied research project titled “Biography of the Innovation Process of Renewable Energies in Germany” tracked and analyzed this widely noted success story. Taking primarily a retrospective approach, participating researchers studied the innovation pathways associated with renewable energy sectors in order to identify lessons to be learned for the purposes of future policy making and implementation approaches within the renewable energy sector. We have also tried to shed light on the supportive as well as impeding factors influencing the innovation processes under study.

This book tackles questions like: What caused the outstanding expansion of wind and solar energy in Germany? Who and what represent the driving forces behind the rise in biomass electricity production and geothermal exploration? Were these just incremental processes or were they guided by policies and political actors? How did the actors involved deal with unanticipated setbacks? What was the role of larger-scale political and social contexts, the nuclear phase-out (“Atomausstieg”) in Germany for example? Did policies and programs provide
enough of a helping hand; what has been the role of economic incentives? How did the parties involved mitigate potential conflicts concerning land-use and other issues? And last but not least, what role did the development of technology itself play in, for example, the photovoltaic sector? What was the role of public research initiatives?

The results of this approach have been evaluated to allow an understanding of the complexity of the innovation pathways involved and of their ups and downs. The analytical and interpretive tool used for the comprehensive analysis of the storyline in each of the renewable energy sectors was the method “Constellation Analysis”, which integrates elements of policy analysis and of Actor Network Theory, the latter of which focuses on the role of artifacts in innovations processes. Moreover, one aim was to generate an interpretation of the behavior of the actors involved, of their relationships and of the embedded contexts, which played an important role.

Unsurprisingly, the complexity of the relevant innovation pathways can be overwhelming. For this reason, the big picture has been carefully distilled into four analytical core categories, using the methodological approach of Constellation Analysis to examine actors, natural elements, technical elements and (semiotic) systems, such as legislation, tax exemptions, etc. As a result, the analysis has been able to identify forces that drive as well as those that impede in the innovation biography of renewable energies.

On the one hand, all renewable energy sectors have been driven to a nearly equivalent extent by national and international stimuli, which are subsequently presented (Chapter 3). This involves such driving forces as crises-triggering societal rethinking, international climate protection policies and research, European renewable energy policy incentives, as well as governmental promotion and sponsorship, which serve as a major source of stimuli. Key players have been the federal Renewable Energy Sources Act and its preceding act, which set the agenda by creating sustainable feed-in tariffs. Important aspects of the permit procedures, amendments to the planning system, environmental regulations and the electricity markets also brought relevant issues to the fore too.

On the other hand, each sector of the German renewable energy deployment shows unique and outstanding characteristics. We present synopses of the innovation pathways of each renewable energy sector, highlighting phase-specific descriptions of the driving and impeding forces in those sectors. Thus we present a brief recent history of the deployment of renewable energies in Germany, each including a sector-specific analysis of the predominant and outstanding features (Chapters 4–8). Each renewable energy sector has been subdivided into distinct phases within the overall development in that sector and each of those phases has been analyzed with reference to the interaction of influencing actors and factors.

Furthermore, the analysis highlights the role of key cross-sectoral influencing factors (Chapter 9), as well as that of policies designed to encourage industries and initiatives; these factors set crucial milestones. An example of a socio-cultural influence was the Chernobyl reactor catastrophe in 1986 and examples of policy
intervention include the German Offshore Wind Strategy of 2002 and the German Climate Protection Program of 2005. Undoubtedly, the German Renewable Energy Sources Act has played a key role, both in fact and in appearance through the mission that underlies it, the policy it embodies and the reliable economic incentives it creates. Itself in force since the turn of the millennium, the Renewable Energy Act was preceded by the federal act known as the “Stromeinspeisungsgesetz” of 1991, which had already successfully set the agenda with respect to the provision of effective electricity feed-in tariffs. And could these innovations really have been triggered with such success without the spirited liberalization of the European electricity markets?

Notable and outstanding phenomena are also at the focus of the discussion of sector-specific innovation pathways described here. Note, for example, the astounding interim slump in biomass use during 2007/2008, coming just after it had enjoyed a definite boost phase. And what were the driving forces associated with the solar (photovoltaic) boom phase that began in 2004? Will this boom continue in view of a recent deliberate reduction of the relevant feed-in tariffs?

It appears that only a few stakeholders might benefit from geothermal energy; could this explain its comparatively modest development in Germany? Is there any viable evidence that innovation in onshore and offshore wind energy have taken separate paths since 2002?

The sectoral branches of renewable energies in the electricity sector feature unique innovation conditions, pathways and dynamics. Yet a certain pattern does seem to emerge: innovation processes do not proceed continuously or linearly, instead, they exhibit phases of depression and setbacks. Phases of highly dynamic innovation may be followed by phases of crisis that pose a challenge for policy making. Despite the distinctive differences among the innovation processes associated with wind, biomass and solar renewable energy, their deployments do have a great deal in common, and we try to sketch out those commonalities as well.

For example, German deployment of biogas (Chapter 4) includes a phase that features a remarkable focus on manure processing, in part as a consequence of German reunification. Technological developments were driven by the feed-in-tariffs mentioned above, these days following in an industrially-shaped development path that also leads toward the integration of biogas into the natural gas infrastructure. Biogas technologies have been driven, to a high degree, by hands-on and application-specific developments on the part of the manufacturers themselves. Yet the dependency on the supply of raw material for biogas results in inherent uncertainties and a multi-faceted complexity associated with the overlying mechanisms of the agricultural markets. A major boom was caused by an amendment of the Renewable Energy Sources Act that provided more attractive economic incentives, while at the same time inadvertently creating major environmental and societal conflicts (biofuel against food debate, etc.).

The solar (photovoltaic) technological approaches (Chapter 5) were labeled from the beginning as “high-tech” innovations. The constellation of actors behind the development of solar power in Germany includes outstanding public-private
partnerships among silicon-producers, solar module and wafer manufacturers, planning engineers, craftsmen, landlords, non-governmental organizations and municipalities. Successful solar energy implementation in Germany is still concentrated on roof-top installations; development of field applications has been effectively delayed by a recognized lack of appropriate sites and by restrictive regulations associated with the Renewable Energy Act. Publicly funded model projects at the local and state level substantially supported solar deployment even when the federal incentives were in trouble.

The use of geothermal heat (Chapter 6) has its roots in cities of the former German Democratic Republic, but at the beginning of the 1990s, legislators missed the chance to integrate this sector into the feed-in-tariffs that promoted renewable electricity generation. As they have since been included, some pilot projects have now been implemented in Germany. However, in the face of remarkable drilling risks and costs and the lack of a broad alliance of motivated actors, the innovation process must still be considered as nascent.

When it comes to wind energy (Chapter 7), the boost phases could not have been more powerful. These were triggered by the dominating policy effects of the guaranteed feed-in-tariffs, combined, inter alia, with subsequent society-focused innovations in the German spatial and environmental planning system and by courtroom decisions, some at the European level. The long-term stable and ongoing implementation and diffusion of wind energy in Germany can now be seen as the consequence of iterative, step-by-step and phase-specific adjustment management. Wind energy is still a quantitative forerunner with respect to the dynamics of renewable innovation and diffusion in Germany; not even the important electricity grid integration and storage debate or the bullying of the coal and nuclear lobbies that preceded them were able to halt the increasingly cost-effective deployment.

Hydropower resources (Chapter 8), also once the leading renewable energy sector and forerunner of sustainable engineering, are limited in Germany. Even that exploitation potential that remains has been decisively restricted by European nature conservation requirements and subsequent policies. Yet, toward the end of their work, but of no little importance, the authors acknowledge the pivotal incentive provided by hydropower for the creation of feed-in-tariffs in Germany, which were triggered by the motivation of political pioneers to improve the revenue of small hydro power facilities.

The final chapter of the book (Chapter 10) provides a discussion of lessons learned so far for the supervision of related innovation processes: provide phase-specific interventions, identify and limit unintended consequences as promptly as possible, integrate different levels of actions and actors, steer the decisive driving forces by ensuring comprehensive synchronisation and by systematic analytical monitoring and amending to allow for a sustainable deployment of renewable energy!

Finally, the results of the underlying research project highlight the heterogeneous complexity and the ups and downs of the innovation biographies of renewable energies. Deployment has, in many ways, involved a successful collaboration on the part of the governmental, private and societal actors involved. Likewise, overarching
framework conditions, technical preconditions and societal influences have played a
decisive role. Hence, there is a constant need for systematic analytical monitoring
and amending on the part of the political arena as well. At the end of the day, only
a comprehensive yet feasible approach of that kind could provide the opportunity to
track down the interdependencies and to allow public, entrepreneurial and civic
policy making that will allow sustainable deployment of renewable energy.
Chapter 2
Introduction to the Methodology

Abstract As renewable energy technologies play an increasing role in international climate protection processes, they also play a key role in driving innovation processes within the energy technology sectors. A cross-sectional analysis of the various renewable energy technologies in Germany was accomplished, using a combination of Constellation Analysis (to map the various actors involved) and the concept of innovation biographies (to interpret the innovation pathways). The research aims at showing what drives or hinders the implementation of a renewable energy technology. The data and information used is based on extensive interviews, relevant literature and Internet research. This combination of methods results in a detailed and empirical account of the elements, actors and processes of each renewable energy sector and their mutual influences.

Keywords Constellation Analysis • Innovation biography • Methodology • Cross-sectional • Political science

2.1 Research Questions and Objectives

The expansion of renewable energies is an important cornerstone of the energy transition aimed for in Germany and beyond. At the same time, renewable energies are increasingly proving to be a driving force in innovation-oriented developments. They have become extremely important for the economy and for technology, which shows in growing sales and employment figures, and in the development of technologies that are geared toward efficient energy utilization and technical innovation.

This raises the question of what conditions and stimuli render innovations in the domain of renewable energy successful and what helps them to become accepted? What accounts for a favorable innovation climate? Which innovation conditions are key to the further expansion of renewable energy in the electricity sector?
This book considers the innovation biography of renewable energies for the generation of electricity in Germany in a cross-sectional analysis. The focus is on the driving forces and restraints that appear in the respective phases of development. These factors are analyzed in order to draw conclusions about the key conditions for innovation. The aim is to provide a detailed account of the development, the progress made in harnessing various energy sources, and their contribution to the generation of electricity. The results are intended to help align the innovation processes and the use of policy instruments for the promotion of renewable energies in an even more focused manner.

The study is targeted at those interested in the relevant constellations of key actors, alliances, driving forces, and restraints, and would like to learn more about the causal system of interaction between societal, technical, ecological and economic influencing factors in the context of renewable energies. This analysis is also relevant to political decision-makers whose tasks include setting the overall course in the context of renewable energies and who are therefore in a position to help unfold their innovation power and economic potential.

2.2 Procedure

In addition to a review of the relevant literature and Internet research, interviews with around 40 selected experts served as an important basis for interpreting the innovation process with its driving forces and restraints.

The relevant factors were arranged according to the time of their occurrence (phase concept) and the role they played in the respective constellations, as well as their significance for the innovation process (process of assessing and interpretation). Constellation diagrams are used as a means of structuring the presentation and contextualizing the complex activities of the actors, lines of motivation and influencing factors. They serve as a visual summary of what is described in detail in the text.

Analysis of the innovation processes (Chapters 4–8) is arranged according to energy sectors (biogas, photovoltaics, geothermal, wind, and hydropower, respectively). We tried to maintain a consistent structure in all of these chapters. In some cases this was not entirely possible because of sector-specific differences.

The sector-specific portrayals are preceded by Chapter 3, which outlines the most important cross-sectoral influencing factors, policies and processes that fundamentally affected all of the sectors analyzed. Contrary to the other sector-specific chapters, in Chapter 3 these factors are arranged according to topics, and not chronologically, so as to avoid repetition.

If certain influencing factors, policies and processes are of particular relevance for a certain sector or if it was thought necessary to describe the effects of a policy on a certain energy sector in greater detail, these points are addressed once more in the context of the respective phases they occurred in within the sector-specific chapters.
2.2.1  A Note on Style

While the hope is that the book will be read in its entirety, it has been structured to accommodate those readers who might only be interested in certain energy sectors. However, the overarching factors and policies are described in Chapter 3. The references are located at the end of each chapter. The web addresses in the references have been shortened to the respective home page.

The relevant legal sources referred to in the text are explained in an “Index of Legal Sources” at the end of the book. The front of the book includes a list of abbreviations used throughout the book. The Système International (SI) has been used where possible. When writing about power in Watts we usually mean electric power, but where we need to distinguish between electric and thermal or calorific power we specify the symbol \( W_e \).

2.3  Methodology Used in the Constellation Analysis

The study is based on the combination of two methodological approaches, the Constellation Analysis (Schön et al. 2007) and the concept of Innovation Biographies (Rammert 2000), as starting points of the analysis.

2.3.1  Constellation Analysis

The Constellation Analysis serves as an interdisciplinary bridging concept for the analysis of complex actor constellations from a multi-disciplinary perspective. It facilitates interdisciplinary communication in the process of analytical research. The object of research – a constellation characterized by actors, policies, socio-economic framework conditions as well as natural and technical elements – enables us to correlate the various disciplines’ views, knowledge and solution approaches.\(^1\)

Division of the innovation process into phases forms the basic heuristic for the Constellation Analysis, in that it creates chronological reference points that are used to map the constellations at hand.

For each phase, the most important elements of the respective constellations are mapped, i.e. recorded and correlated, and graphically represented. These diagrams of the constellations are a simplification of the complex field of actors and interactions. They precede the detailed textual analysis of the respective phase. The constellation diagrams serve as the basis for analyzing the relations between the constellation elements and their effects. In addition, they enable us to elaborate

\(^1\)For a detailed description of the methodological approach of the Constellation Analysis, see Schön et al. (2007).
the constellation’s characteristics and their central driving or restricting forces. Finally, the characteristics and dynamics of the constellations are subjected to a comprehensive interpretation.

Application of the method is characterized by an iterative procedure. This comprises several consecutive steps or steps that refer to each other. Back-references between these steps are inevitable. From step to step – the creation of a chronology, the division into phases and mapping of the constellation elements, right up to the interpretation of the constellation – the degree of abstraction increases.

### 2.3.2 Constellation Elements

We focus on four different types of elements that make up the constellations: social actors, technical elements, natural elements and signs/symbols. The different elements are marked by different colors and graphical representations (see Fig. 2.1).

Actors are individual persons, groups of actors and institutions. All artifacts (material products) are referred to as technical elements. Natural elements include natural resources (water, soil, air), animals and plants, the landscape, and natural phenomena. Signs and symbols comprise, for example, concepts, standards, laws, prices, communication and lead principles.

![Fig. 2.1 Constellation elements (acc. to Schön et al. 2007)](image)

### 2.3.3 Relations

Relations denote existing links between two or several elements (Fig. 2.2).

There are the following different types of relations:

- Simple relations: elements are more or less closely connected.
- Targeted relations: an element specifically impacts one or several other elements (targeted relations can be positive/stimulating or negative/inhibitory).
- Incompatible relations: two or several elements have an antagonistic effect on each other; the intentions are incompatible.
- Conflicting relations: there is a conflict between two or more elements, which reflects in one element expressly and intentionally acting against one or several other elements.
- Resistive relations: one element offers passive, non-explicit resistance to an expectation or ascription from other elements.
2.3 Methodology Used in the Constellation Analysis

2.3.4 Context

Each constellation is embedded in a context. Context conditions are cross-sectoral framework conditions and superordinate processes that affect all aspects of society and influence not only individual elements within the constellation but the constellation as a whole. These may be political or strategic actions taken at the international level, suddenly occurring phenomena, variations in the availability of resources, political changes of power, cultural convictions, academic paradigms or important events that affect public awareness. Conditions that are classified as context elements form the backdrop or an overall atmosphere that fuel certain developments. Context in this sense favors the development and introduction of certain innovations while complicating that of others.

2.3.5 The Concept of a Biography of Innovation

The methodology applied to analyse innovation processes originates from current innovation and governance research which devised models of innovation theory. They are based on empirical studies, which focus on the process of innovation and on political processes. Some of the approaches and analyses which drew conclusions similar to those in this study shall be briefly outlined here.

2.3.5.1 Innovation Biography

The term “innovation biography” as used in this book is derived from Rammert’s (2000) concept of innovation biographies. We have applied theories and methods used in sociological biography research to the exploration of innovation processes. Hence, a typical feature of our approach is that it focuses on the development, which is expressed in the chronological order of the stimuli and events.

The approach of innovation biographies strives primarily to identify driving forces and characteristic patterns, the role of actors and groups of actors, socio-economic, technical and natural factors in the innovation process, as well as