Renewable Energies in Germany's Electricity Market

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A Biography of the Innovation Process

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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
BMWA	Bundesministerium für Wirtschaft und Arbeit (from 2002 till 2005)
BMWi	Bundesministerium für Wirtschaft und Technologie (since 2005)
BNatSchG	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
CO_2	Carbon dioxide
CSU	Christlich Soziale Union
DASA	Deutsche Aerospace Aktiengesellschaft, today: Daimler Chrysler Aerospace AG

DBU	Deutsche Bundesstiftung Umwelt
dena	Deutsche Energie-Agentur
DEWI	Deutsches Windenergie-Institut
DFS	Deutscher Fachverband Solarenergie e.V.
DFVLR	Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt
DGS	Deutsche Gesellschaft für Sonnenenergie
DGW	Deutsche Gesellschaft für Windenergie
DIW	Deutsches Institut für Wirtschaftsforschung
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DEM	Deutsche Mark
DMG	Deutsche Meteorologische Gesellschaft
DNR	Deutscher Naturschutzring
DPG	Deutsche Physikalische Gesellschaft
DtA	Deutsche Ausgleichsbank
EEG	Erneuerbare-Energien-Gesetz
EFG	Edge-defined Film-fed Growth
EFP	Energieforschungsprogramm
EGS	Enhanced Geothermal System
EnBW	Energie Baden-Württemberg AG (utility)
EU	European Union
EuGH	Europäischer Gerichtshof
EWG	Europäische Wirtschaftsgemeinschaft
FAL	Bundesforschungsanstalt für Landwirtschaft, Braunschweig
FDP	Freie Demokratische Partei
FFH	Flora-Fauna-Habitat
FhG	Fraunhofer Gesellschaft
FNR	Fachagentur Nachwachsende Rohstoffe
FRG	Federal Republic of Germany
FVS	ForschungsVerbund Sonnenenergie
GAU	Größter Anzunehmender Unfall
GbR	Gesellschaft bürgerlichen Rechts
GDR	German Democratic Republic
GFZ	GeoForschungsZentrum Potsdam
GGA	Institut für Geowissenschaftliche Gemeinschaftsaufgaben
GmbH	Gesellschaft mit beschränkter Haftung
GROWIAN	Großwindanlage
GT	Geothermie
GTN	Geothermie Neubrandenburg GmbH
GtV	Geothermische Vereinigung
GtV-BV	Geothermische Vereinigung – Bundesverband Geothermie e.V.
GWh	Gigawatt per hour
HDR	Hot Dry Rock
HFG	Helmholtz-Gemeinschaft deutscher Forschungszentren
HFR	Hot Fractured Rock
HVDC	High Voltage Direct Current

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_{el}	Megawatt, electric capacity
MWh	Megawatt per hour
MWp	Megawatt, peak
MW_{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

Chapter 1
Introduction

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

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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 promplty 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?

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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_{el}).

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.

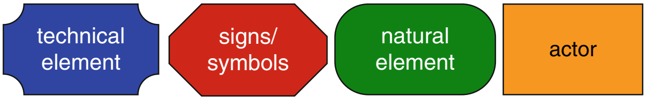

Fig. 2.1 Constellation elements (acc. to Schön et al. 2007)

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.

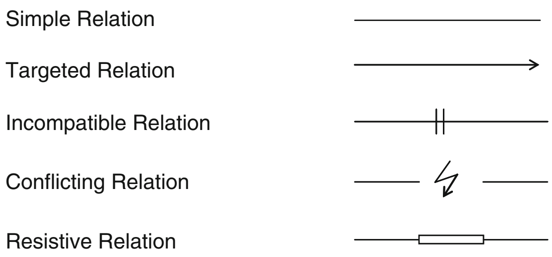

Fig. 2.2 Relations (acc. to Schön et al. 2007)

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