Citizen participation, project management, and behaviorally informed policy – essays on the sustainable transition of the German energy sector

vorgelegt von
Diplom-Kaufmann, Diplom-Volkswirt
Özgür Yildiz
geboren in Berlin

von der Fakultät VII – Wirtschaft und Management
der Technischen Universität Berlin
zur Erlangung des akademischen Grades

Doktor der Wirtschaftswissenschaften
– Dr. rer. oec. –

genehmigte Dissertation

Promotionsausschuss:

Vorsitzender:	Prof. Dr. Christian von Hirschhausen (TU Berlin)
Gutachter:	Prof. Dr. Georg Meran (TU Berlin)
Gutachter:	Prof. Dr. Jens Lowitzsch (Europa-Universität Viadrina)

Tag der wissenschaftlichen Aussprache: 21.07.2016

Berlin 2016

Danksagung

Diese Dissertationsschrift wäre ohne die Mithilfe vieler Personen nicht möglich gewesen, daher möchte ich die Gelegenheiten nutzen, mich an dieser Stelle bei diesen Unterstützern zu bedanken.

Ein erster großer Dank gebührt Prof. Dr. Georg Meran, der mir nicht nur die Möglichkeit eröffnete, dieses Dissertationsvorhaben überhaupt zu realisieren, sondern mir ebenfalls umfangreiche inhaltliche Freiheiten einräumte, mit seinem Rat bei inhaltlichen Fragen stets beiseite stand und mit seiner Offenheit gegenüber neuen Themen und Forschungsansätzen mich dazu inspirierte, das Themenfeld der Verhaltensökonomik aufzugreifen und in dieser Arbeit zu vertiefen. Beispielhaft ist seine persönliche und inhaltliche Unterstützung bei der Akquise des von der Volkswagen Stiftung geförderten Forschungsprojektes zu nennen, das die Grundlage für zwei Arbeiten dieser Dissertationsschrift bildete. Ich hoffe, dass meine Arbeit am Fachgebiet nur der Auftakt für weitere gemeinsame Forschungsarbeiten und Projekte war.

Ein großes Dankeschön möchte ich ebenfalls dem gesamten Team des Fachgebiets für Umweltökonomie der TU Berlin aussprechen. Prof. Meran und Eva Aust haben mit ihrer Fürsorge für alle Mitarbeiter eine familiäre Atmosphäre geschaffen, so dass man sich sofort wohl fühlte und trotz der anspruchsvollen inhaltlichen Aufgaben bei persönlichen Anliegen immer jemanden zum Zuhören hatte. Auch Dr. Nadine Wittmann ist in diesem Rahmen namentlich zu nennen, denn sie unterstützte mich mit ihrer Hilfsbereitschaft bei fachlichen Fragen und hatte ebenfalls die Initiative zu einer gemeinsamen Publikation, die Bestandteil dieser Dissertationsschrift ist.

Prof. Dr. Jens Lowitzsch möchte ich ebenfalls meinen großen Dank ausdrücken. Zunächst möchte ich mich dafür bedanken, dass er sich dazu bereit erklärte, als Gutachter zur Verfügung zu stehen. Vielmehr möchte ich jedoch meine Anerkennung dafür ausdrücken, dass er mit seinem Interesse und seinem leidenschaftlichen Einsatz für Bürgerbeteiligungsmodelle im Energiebereich stets die Bereitschaft für einen fachlichen Austausch hatte. Hierdurch konnte ich mich sowohl inhaltlich weiterentwickeln als auch persönlich von seiner Erfahrung lernen. Auch hier hoffe ich, dass der Austausch, der im Zuge der Erarbeitung meiner Dissertationsschrift entstanden ist, den Beginn für viele erfolgreiche Forschungsarbeiten bildet.

Darüber hinaus möchte ich ebenfalls die inhaltliche Unterstützung weiterer Personen hervorheben. Prof. Dr. Christian von Hirschhausen danke ich für die Übernahme der

Funktion des Vorsitzenden des Promotionsausschusses. Prof. Dr. Reimund Schwarze hat mir die Möglichkeit eröffnet, durch meine Mitarbeit am recap15-Projekt viele nette Kolleginnen und Kollegen an der Europa-Universität Viadrina Frankfurt (Oder) kennenzulernen und dabei die Themenfelder der internationalen Klimaverhandlungen und der Verhaltensökonomik zu vertiefen. Darüber hinaus hatte Prof. Schwarze die Initiative zu einem gemeinsamen Aufsatz, der in dieser Dissertationsschrift enthalten ist. In diesem Zusammenhang richtet sich mein Dank neben Herrn Prof. Schwarze und Herrn Prof. Meran besonders an Dr. Gabriela Michalek für ihren unermüdlichen Einsatz als Lead-Autorin dieser Arbeit. Weiterhin bedanken möchte ich mich bei Prof. Dr. Uwe Arnold für die erfolgreiche Zusammenarbeit bei der Erarbeitung einer gemeinsamen Publikation und die Kooperation im Rahmen des BMBF-Forschungsprojektes „RePro – Ressourcen vom Land“. Abschließend möchte ich mich stellvertretend bei Dr. Susanne Schön für die Unterstützung der Kolleginnen und Kollegen aus dem RePro-Projekt bedanken. Allesamt haben mir den Einstieg in die Wissenschaft und Forschung durch ihre offene und hilfsbereite Art sehr leicht gemacht und mir bei Fragen helfend zur Seite gestanden. Nicht unerwähnt bleiben sollten zudem Kolleginnen und Kollegen vom inter3 Institut für Ressourcenmanagement und dem Forschungsnetzwerk „Genossenschaften in der Energiewende“ mit denen ich einen konstruktiven inhaltlichen Austausch pflegte sowie das BMBF und die Volkswagen Stiftung, die mit ihrer finanziellen Förderung die von mir bearbeiteten Forschungsprojekte überhaupt erst möglich gemacht haben.

Neben den zahlreichen Unterstützern aus Forschung und Wissenschaft möchte ich mich zum Schluss bei meiner Familie und Freunden danken. Drei Menschen gebührt dabei die größte Anerkennung: meinen Eltern Ali und Aliye Yıldız und meiner Frau Kintija. Euch möchte ich aus ganzem Herzen den tiefsten Dank für eure Unterstützung und Liebe aussprechen. Ihr habt mich bedingungslos in meiner Arbeit bestärkt, immer an mich geglaubt und wart immer für mich da. Meinen Eltern möchte ich zudem sagen, dass ihr mir stets ein Vorbild seid und mich überhaupt erst zu dem Menschen gemacht habt, der ich heute bin. Euch widme ich diese Dissertation.

Berlin, August 2016

Özgür Yıldız

Liste der Einzelarbeiten/ List of included publications

Diese Dissertation besteht aus insgesamt sechs Einzelarbeiten: Vier Aufsätze, die in begutachteten wissenschaftlichen Fachzeitschriften erschienen sind, eine Arbeit, die in einer Diskussionspapier-Serie erschienen ist, sowie ein unveröffentlichtes Manuskript. Nachstehend werden die bibliographischen Informationen zu den veröffentlichten Einzelarbeiten aufgeführt.

This dissertation includes six different manuscripts: Four manuscripts that were published in peer-reviewed scientific journals, a manuscript that was published in a discussion paper series, and a manuscript that has not been published or submitted to a scientific journal yet.

Die Einzelarbeiten sind nach der Reihenfolge in dieser Dissertationsschrift geordnet./ The included manuscripts are listed according to their order in this dissertation thesis.

1)
Yildiz, Ö. (2014): Financing renewable energy infrastructures via financial citizen participation – The case of Germany. In: *Renewable Energy*, 68, 677-685. http://dx.doi.org/10.1016/j.renene.2014.02.038

2)
Yildiz, Ö. (2013): Energiegenossenschaften in Deutschland–Bestandsentwicklung und institutionenökonomische Analyse. In: *Zeitschrift für das gesamte Genossenschaftswesen*, *63*(3), 173-186. http://dx.doi.org/10.1515/zfgg-2013-0303.

3)
Wittmann, N./Yildiz, Ö. (2013): A microeconomic analysis of decentralized small scale biomass based CHP plants – The case of Germany. In: *Energy policy*, *63*, 123-129. http://dx.doi.org/10.1016/j.enpol.2013.05.069.

4)
Arnold, U./ Yildiz, Ö. (2015): Economic risk analysis of decentralized renewable energy infrastructures – A Monte Carlo Simulation approach. In: *Renewable Energy*, *77*, 227-239. http://dx.doi.org/10.1016/j.renene.2014.11.059.

5)

Michalek, G./ Meran, G./ Schwarze, R./ Yildiz, Ö. (2015): Nudging as a new “soft” tool in environmental policy. An analysis based on insights from cognitive and social psychology. (No. 21). Discussion Paper Series recap15 – No. 21, European University Viadrina, Frankfurt (Oder).
URL: https://www.europa-uni.de/de/forschung/institut/recap15/downloads/recap15_DP021.pdf.

6)

Yildiz, Ö. (o.J.): Public-private partnerships, incomplete contracts, and distributional fairness – when payments matter. Unveröffentlichtes Manuskript/ *unpublished manuscript*.

General summary[1]

This thesis addresses through six essays questions from a managerial and policy perspective in the context of the transition of the German energy sector toward a broader use of renewable energy technologies ("Energiewende"). In addition, this thesis will also deal implicitly with questions of transdisciplinary research in the context of the "Energiewende".

The different essays include a variety of methods, i.e.,

- literature-based meta-analysis,
- theoretical analysis through microeconomic modeling,
- the rationale of new institutional economics, and
- the use of Monte Carlo simulation techniques to address the specific managerial question of risk management.

Furthermore, two essays also include an additional feature by integrating insights from behavioral economics into the analytical framework of the respective essays.

In detail, the first essay provides an overview on relevant actors in the German renewable energy sector and derives insights on the connection between actors, technology, and the organizational framework of business models through meta-analysis. The second essay complements this overview by conducting a theoretical analysis of renewable energy cooperatives with the help of the new institutional economics rationale. The third and fourth essays focus on tools for project assessment. Here, the third essay offers an approach for the optimization of the input of biogas plants by applying a nested constant elasticity of substitution production function approach. The fourth essay presents a developed tool for the risk analysis of renewable energy projects using Monte Carlo simulation. Here, the transdisciplinary aspect will be tackled because actors from nonacademia were involved in developing the tool.

The particular characteristic of the fifth and sixth essays is that both focus particularly on insights from behavioral economics. While the fifth essay develops a toolset for energy and environmental policy through a meta-analysis of insights from cognitive sciences that goes beyond conventional policy instruments (e.g., monetary incentives and mandates), the sixth essay uses findings from behavioral sciences on so-called social preferences to conduct a theoretical, microeconomic analysis of the effects of different ownership options in the context of public private partnerships.

[1] The author would like to thank Dr. Ian Mcnaught, text editor at Cambridge Proofreading LLC (http://proofreading.org/), for the language-editing of this chapter.

In the end, this thesis reviews the findings and comes to the conclusion that a holistic analysis approach, as presented here, is of particular importance for the analysis and governance of the “Energiewende” as central aspects such as the involved actors, their determinants for decision-making, technical characteristics, frame-setting institutions, and the wider social context are in a vital interaction.

Keywords

energy transition; citizen participation; energy cooperatives; risk management; energy policy; environmental policy; behavioral economics; new institutional economics; public-private partnerships; incomplete contracts

Zusammenfassung

Diese Dissertationsschrift untersucht verschiedene betriebswirtschaftliche sowie umwelt- und wirtschaftspolitische Fragestellungen im Kontext der Energiewende. Des Weiteren werden Themen wie Transdisziplinarität und die Gestaltung transdisziplinärer Forschungsansätze im Kontext der nachhaltigen Transformation des Energiesektors in Deutschland im Verlauf dieser Arbeit ergründet.

Die Dissertationsschrift umfasst sechs verschiedene Aufsätze, deren Forschungsansätze sich jeweils in ihrer Methodik unterscheiden. Demnach beinhaltet diese Arbeit

- literaturbasierte Meta-Analysen,
- theoretische Untersuchungen mittels mikroökonomischer Modelle,
- theoretische Auseinandersetzungen unter Rückgriff auf das Argumentationsgerüst der Neuen Institutionenökonomik sowie
- die Anwendung von Monte Carlo-Simulationstechniken zur Entwicklung eines Instruments zur Risikoanalyse.

Zudem setzen zwei Aufsätze den Gedanken der Transdisziplinarität um, indem Akteure aus der Praxis sowohl im Zuge der Entwicklung der Fragestellung als auch während der Problemlösung einbezogen werden.

Im Detail vermittelt der erste Aufsatz einen Überblick über die zentralen Akteure bei der Finanzierung von erneuerbaren Energien in Deutschland und zeigt im Zuge der Analyse Zusammenhänge zwischen Akteursgruppen, zugrunde liegender Technologie und dem betrieblichen Organisationsmodell. Der zweite Aufsatz ergänzt den ersten Beitrag durch eine theoretische, institutionenökonomische Analyse zur Untersuchung von Energiegenossenschaften.

Der dritte und vierte Aufsatz stellen entwickelte Instrumente zur Wirtschaftlichkeits- und Risikoanalyse von nachhaltigen Infrastrukturen zur Nutzung erneuerbarer Energiequellen. Hierbei beinhaltet der dritte Aufsatz ein Verfahren zur (Kosten-) Optimierung des Substrateinsatzes von Biogasanlagen mittels verschachtelter Produktionsfunktionen. Im Rahmen des vierten Aufsatzes wird ein Instrument zur Risikoanalyse vorgestellt, das durch die Anwendung von Monte Carlo-Simulationstechniken die parallele Variation mehrerer Eingangsparameter ermöglicht. Neben den erläuterten methodischen und inhaltlichen Merkmalen wird im Rahmen der beiden soeben beschriebenen Aufsätze der Aspekt der Transdisziplinarität besonders hervorgehoben, indem Akteure aus der Praxis aktiv in den Forschungsprozess involviert wurden.

Das besondere Charakteristikum des fünften und sechsten Aufsatzes ist der Bezug zur Verhaltensökonomik. Während der fünfte Beitrag einen Ansatz zur Erweiterung des etablierten umweltpolitischen Instrumentariums unter Verwendung von Erkenntnissen aus dem Bereich der Kognitionsforschung entwickelt, greift der sechste Essay auf Forschungsergebnisse zu sogenannten sozialen Präferenzen zurück und wendet diese auf die theoretische Auseinandersetzung zur Verteilung von Eigentumsrechten im Rahmen von öffentlich-privaten Partnerschaften an.

Die Dissertationsschrift endet mit einer Zusammenfassung der Ergebnisse und stellt nochmals heraus, das für die komplexen Problemstellungen im Rahmen der Energiewende ein holistischer Analyseansatz notwendig ist, um die verschiedenen Dimensionen der relevanten Fragen zu adressieren.

Schlagworte:

Energiewende; Bürgerbeteiligung; Energiegenossenschaften; Risikomanagement; Energiepolitik; Umweltpolitik; Verhaltensökonomik; Neue Institutionenökonomik; öffentlich-private Partnerschaften; unvollständige Verträge

Table of contents

List of figures

List of tables

List of abbreviations

Note:

According to the general formal guidelines of a doctoral thesis, a list of abbreviations is included if necessary. However, since this doctoral thesis is a cumulative compilation of the author’s essays, a list of abbreviations is included at the introduction to every chapter where abbreviations are used as this arrangement improves the clearness for the reader.

List of symbols

Note:

According to the general formal guidelines of a doctoral thesis, a list of symbols is included if necessary. However, since this doctoral thesis is a cumulative compilation of essays of the author, a list of symbols is included at the introduction to every chapter where formal models are included as this arrangement improves the clearness for the reader.

Chapter 1: Introduction and research purpose[2]

1.1. Problem statement

Climate change is one of the major challenges of modern time. In this context, one of the main topics of the debate is the aim to limit the rise in global average temperature to 2 °C. Accordingly, countries all over the world set ambitious targets to reduce greenhouse gas emissions, to improve the efficiency with which private individuals and industry use energy for their purposes, and to change the portfolio of energy supply technologies, i.e., increase the share of renewable energy for electricity production (Böhringer et al. 2009).

In Germany, a major political project in this regard is the transformation of the energy sector toward a broader use of low-carbon technologies, the so-called “Energiewende”. Starting in the 1970s with the first discussions about alternative strategies of energy policy that go beyond nuclear and fossil fuels, the German “Energiewende” now is one of the most important reform projects of current times related to a more sustainable energy system, offering several lessons for other countries that are elaborating ways to change their energy system to a structure that is based to the largest possible extent on renewable energy sources. With the particular measures undertaken having implications for the technical, political, and socioeconomic domain, the “Energiewende” is at the same time also one of the most controversially discussed reform projects toward a more sustainable economic development. Hence, action plans are screened and revised steadily to cope with the challenges of the transition process. Among these challenges are technical constraints (e.g., energy security, lack of storage technologies), socioeconomic aspects (e.g., social costs of different transition strategies, management issues of running infrastructures such as risk management, financing, and questions regarding intra- and interorganizational processes), and governance[3] questions (von Hirschhausen 2014). The just-mentioned problem sets are the more challenging as the production of energy based on renewable sources is geographically more dispersed, the role of established actors changes as boundaries between unregulated and regulated tasks become blurred, and

[2] The author would like to thank Dr. Ian Mcnaught, text editor at Cambridge Proofreading LLC (http://proofreading.org/), for language-editing of this chapter.

[3] The term governance focuses here on the public authority’s ability to set the framework for all processes and actors within its sphere of control, i.e., to make and enforce rules, strategies, measures, etc. (Fukuyama 2014).

new actors enter the energy sector and succeed in influencing energy policy (Agrell et al. 2013).

In addition to these challenges, a second objective in the context of the “2 °C climate target”, i.e., the aim to enhance the efficiency in energy consumption of households and industry, is impeded by additional constraints. Among these problems are systemic behavioral biases of private consumers, which lead to a slow diffusion of energy-efficient products on a household and individual level, a general lack or an imperfect provision of information on energy-efficient technologies, and principal–agent issues in residential settings where there can be a discrepancy between a party that makes a decision relating to energy use (e.g., the owner of a property; a land owner) but does not benefit from this decision as he is not the user (Gillingham and Palmer 2014).

Hence, these developments and problem sets have several implications for the policy domain, for questions regarding the operational control of the businesses, and also for the scientific community that analyzes relevant problems and develops recommendations for action but at the same time has to adapt its own tools and methods to the framework set by the subject of study. The challenges of these three domains that are relevant for the further course of this thesis will be described in detail in the following subsections.

1.1.1. Challenges from a management perspective

In the context of the “Energiewende”, decentralized small-scale infrastructures and various approaches aimed at involving citizens in the renewable energy sector recently received particular importance. Here, these approaches serve as a vehicle for private individuals to participate in (local) energy policy for financial (i.e., gains from investing in renewable infrastructures; reductions of energy costs), normative (i.e., concerns on environmental aspects such as climate change and sustainability; concerns on the dominant role of established suppliers in the energy sector), and hedonic reasons (i.e., enjoying social relationships within community activities; excitement of being an investor and realizing an energy project) (Dóci and Vasileiadou 2015). Examples are so-called community energy initiatives (Rogers et al. 2008; Walker and Devine-Wright 2008), energy villages (Zoellner et al. 2011), collective ownership models such as energy cooperatives (Yildiz et al. 2015), and grassroots initiatives (Seyfang and Smith 2007; Middlemiss and Parrish 2010).

The entrance of citizens as investors and nonprofessional entrepreneurs in the energy sector and further aspects such as the technical characteristics of renewable resources and the necessary equipment lead to several intraorganizational, i.e., managerial, challenges.

First of all, private individuals that initiate local, small-scale renewable energy projects normally lack entirely or dispose of only little specific know-how in developing and operating a renewable energy project (Busch and McCormick 2014). Furthermore, renewable energy projects are regularly so-called Greenfield projects, so that risks inherent to project finance such as technical, operational, contractual, market, and political risks limit project viability and consequently also impede the raising of capital. These concerns are further aggravated due to the limited know-how of citizens regarding managerial issues (Böttcher 2009). Consequently, risk valuation and risk management are of high importance to analyze project viability, guarantee the highest possible degree of security for investors, and to display the project's debt repayment capability for lenders. In this regard, various tools such as sensitivity analysis exist, but most of them only partly consider the complexity of renewable energy projects (Borgonovo et al. 2010). Hence, there is a strong requirement for the development of suited viability and risk analysis tools that address the complexity of renewable energy projects, but at the same time are nonetheless simple in the presentation of results to respond to the just-described concerns.

In addition to the challenge of project viability and risk management, the realization of a renewable energy project is further complicated by the requirement to coordinate various stakeholders, all of them pursuing to some extent their own objectives. Among these actors are the project sponsors (e.g., investing citizens), lenders, contractors, operators, (resource) suppliers, and output consumers. Hence, a suited organizational model from the complex legal and financial structures has to be developed (Farrell 2003).

In this context, questions related to the new institutional economics literature are of particular importance. First, transaction costs (e.g., Williamson 1979; Williamson 1985) that accrue along the value-added chain of a renewable energy infrastructure represent a major challenge from an intraorganizational perspective. Existing organizational models from market transactions as the loosest and a hierarchically integrated firm as the tightest form cope with various dimensions of transaction costs, depending on the characteristics of a transaction, i.e., specificity, uncertainty, and frequency. Hence, project initiators can decide for a transaction cost-efficient organization form (Altman et al. 2007). Second, agency problems and the menace of opportunistic behavior also significantly influence decisions on the organizational form of a renewable energy project. Here, the literature on so-called "incomplete contract" theory (Grossman and Hart 1986; Hart and Moore 1990) provides a framework to deal with agency problems and analyze the investment incentives of various ownership constellations. In the context of renewable energy projects, this is relevant as the multiplicity of involved parties in a project and the need for coordinated specific investments can only be realized when the organizational setting provides appropriate incentives for investment (e.g., Abdala 2008; Alexander et al. 2012).

To sum up, there is a requirement for sophisticated management tools to assess economic viability and risks of a renewable energy project so that financing of sustainable infrastructures is facilitated (e.g., Arnold and Yildiz 2015). Furthermore, organizational models have to be developed to deal with the above-mentioned intraorganizational constraints. An approach might be to detect conflicts of interest among stakeholders before the investment phase and try to set aside potential conflicts by appropriate organizational methods that balance interests. So-called energy cooperatives and similar organizational models might be a solution as they are characterized by a high diversity among members but it has to be clarified whether the coordination and efficiency of infrastructures can be increased through these cooperative business models (Yildiz et al. 2015).

1.1.2. Challenges from a policy perspective

From a superordinate governance, i.e., policy perspective, the developments in the context of the "Energiewende" also have significant implications as policy makers now have to deal with and set the frame for "*a more cooperative, multi-actor and bottom-up distributed model, linking national policy to local activism and providing spaces for innovation in both the process and form of carbon reduction activity*" (Walker et al. 2007: 65). In practice, however, mainly normative governance approaches consider this aspect insufficiently so that realized formal institutional arrangements[4] do not provide a framework that allows actors to cope with agency problems, possible opportunistic behavior of other actors, and insufficient incentive and control systems.

[4] In general, the term "institution" includes in the context of economic research formal (e.g., laws, property rights) and informal (e.g., norms, values) rules that set the frame for the interaction of agents (Hodgson 1998).

Hence, the classic paradigm of environmental economics to obtain the desired objectives through a package of appropriate environmental instruments falls short in this regard so that new governance approaches are required (e.g., Meadowcroft 2009; Markard et al. 2012).

In the light of the just-mentioned problem and the requirement for new governance approaches, it is particularly important to reconsider the determinants of individual decision making in the context of governance and policy. Standard economics (i.e., neoclassical economics) assumes behavioral traits that might provide a sound rationale and apposite predictions in some scenarios, particularly in competitive market environments (e.g., Bowles 1998; Falk 2003). Among these assumptions, subsumed within the hypothetical figure of *homo economicus*, are behavioral patterns such as self-interest (i.e., caring only about personal own utility), the focus on monetary payoffs in utility assessments, and consistent preferences over time (Gintis 2000).

However, insights from social and cognitive sciences as well as experimental economics and field studies show that depending on the decision context, behavioral patterns beyond the characteristics of *homo economicus* can be relevant for economic and policy analysis. According to this, the explanatory power of economic and policy analysis, the accuracy of its predictions, and recommendations for action can be improved by including several behavioral patterns that can be regularly observed in specific contexts as factors determining individual decision making (Manner and Gowdy 2010; Zarri 2010). Among these patterns, all of them being research strands within so-called behavioral economics, are cognitive limitations (e.g., Simon 1955; Kahneman 2003), social preferences (e.g., Fehr and Schmitt 1999; Bolton and Ockenfels 2000), and systematic biases such as loss aversion (e.g., Kahneman and Tversky 1979/ 1982), the endowment effect (e.g., Knetsch and Sinden 1984; Kahneman et al. 1990); and hyperbolic discounting (e.g., Kirby and Herrnstein 1995; Streich and Levy 2007).

A major field of application for the just-described insights on systemic behavioral patterns that deviate from the assumptions of standard economics is the question of individual behavior regarding energy-efficiency decisions. Here, the so-called energy-efficiency paradox describes a "*gap between current and optimal (cost-effective) energy use and thus conservation.*" (Gsottbauer and van den Bergh 2011: 278). In this regard, market failures such as the lack of public concern for energy issues and limited information can explain why established political measures such as price incentives in some cases are not as effective as theoretically projected to motivate individuals toward a more energy-efficient behavior. However, in addition to market failures, behavioral phenomena such as risk aversion and habits can also contribute to the analysis of the energy-efficiency paradox as these behavioral patterns can explain why individuals tend to keep their status quo instead of investing in a more energy-efficient and therefore in the long run cheaper technology (Gsottbauer and van den Bergh 2011).

Besides the question of inducing a more energy-efficient behavior among individuals, further areas of application exist where it is promising to extend and modify established analysis methods and policy measures.

A first example in this regard is the analysis of social dilemma scenarios, voluntary contributions, and cooperative behavior in the context of the provision of public goods. Here, social preferences can significantly change individual motivations for contributions and therefore the outcomes of social dilemma problem sets (e.g., Lange and Vogt 2003; Buchholz and Peters 2008; Johansson-Stenman and Konow 2010). Furthermore, the use of monetary incentives in the context of public good provision has to be considered with caution as it might lead to a crowding-out of voluntary contributions and cooperative behavior that is socially motivated (e.g., Bowles and Hwang 2008; Gowdy 2008; Bowles and Polanía-Reyes 2012; Carlsson and Johansson-Stenman 2012).

A further example, that ties the discussion of challenges from an intraorganizational perspective, is the lack of coordination among involved decision-makers and actors that ultimately impedes a successful implementation of renewable energy infrastructures. This problem set is in various ways also a concern for policy makers. First, policy sets the legal frame for actors that are involved in the renewable energy sector. Second, and of particular interest from a governance perspective, policy decides on fundamental governance issues such as the question of assigning the rights to decide on the siting and characteristics of renewable energy projects on the regional or federal (i.e., central) level (e.g., Lülfesmann 2002) or the question of providing a service or realizing a renewable energy project through privatization, a public private partnership or on the public's own authority (Hart et al. 1997; Hart 2003). Against this background, the new institutional economics literature provides substantial insights on the implications of different organizational forms on the quality of a provided service (e.g., from an investment incentive and cost-efficiency perspective). Hence, it is of interest to analyze whether the new findings on systematic behavioral patterns beyond the standard economic model are relevant to theoretical analysis and policy making.

To conclude, it is essential from a governance and policy analysis perspective to understand how individuals make decisions in complex contexts and how individual decision making interacts with the social context in which it is embedded. Only a holistic approach of measures considering the effects of incentives and other influencing aspects such as social preferences, human cognition and decision-making, institutions and the wider social context, and the strategic interaction of these patterns can provide a sound base for policy makers to govern the sustainable transition of the energy sector thoroughly (e.g., Rommel 2015; Weimann 2015).

1.1.3. Challenges from a scientific perspective

The third main problem area or respectively important challenge in the context of the analysis of the energy sector transformation and sustainability transitions in general deals with conceptual and methodical aspects from a scientific perspective.

As can be seen from the descriptions above, problem sets in the context of the "Energiewende" as well as in environmental and energy economics and policy in general include various challenging characteristics. According to this, questions related to energy and environmental policy address various domains, i.e., social, ecological, and economic. Consequently, scientific analysis and recommendations for policy have to consider a trade-off between those dimensions when defining criteria, aims, and solutions for a specific problem. Further challenging characteristics are the complexity of problem sets, which is partly due to the manifold domains that are concerned by questions related to the environment and to energy, and the long underlying time horizon, which in turn again raises the degree of complexity (Weber 2013).

Considering this myriad of attributes from various domains that characterize the challenges in the context of the "Energiewende", a requirement for new approaches in science to analyze these problems is apparent. The insights on behavioral economics provided above (see section 1.1.2.) are just one example where new insights from other disciplines on the characteristics of the study object led to adaptations regarding methodological aspects.

Besides this implication for the scientific community toward a more interdisciplinary approach, the problem scenario of the "Energiewende" also calls for more transdisciplinarity as research strategy. As a comparably new paradigm in research, transdisciplinarity is "*characterized by the integration of scientific and nonacademic knowledge for complex problem solving*" (Enengel et al. 2012: 106).[5] Therefore, it is particularly suited to analyze complex problems in environmental and energy research as these fields, characterized by a human–technology–environment nexus, require a knowledge exchange among actors from theory (i.e., academia) and actors from practice to tackle existing problem sets successfully (Ritter et al. 2010).

Through this cross-fertilization, transdisciplinarity promises on the one hand a greater impact of research on society and on the other hand an improvement in research quality as research questions and solutions can be developed more precisely. To realize these synergy effects of transdisciplinarity, research methods and analysis can include actors from practice in three stages: (i) as a consulting party when identifying problem sets and defining the research questions, (ii) during the process of information gathering to develop and feed a model, and finally (iii) directly in the analysis process to let practitioners participate in the stage of knowledge coproduction (Enengel et al. 2012). Hence, the challenge is to find a strategy when and through which of the just-mentioned processes it is most suitable to integrate nonacademia actors into research and scientific analysis.

With this description of challenges from a scientific perspective, the problem statement that is underlying to this thesis ends. Figure 1.1. (**Fig. 1.1.**) summarizes the main findings from the outlined three domains that impose challenges for research in the context of the "Energiewende" as well as in the context of environmental and energy economics and policy and illustrates the topics that will guide this thesis.

[5] The spelling of the quotation has been adapted to American English to be consistent with the format of this thesis.

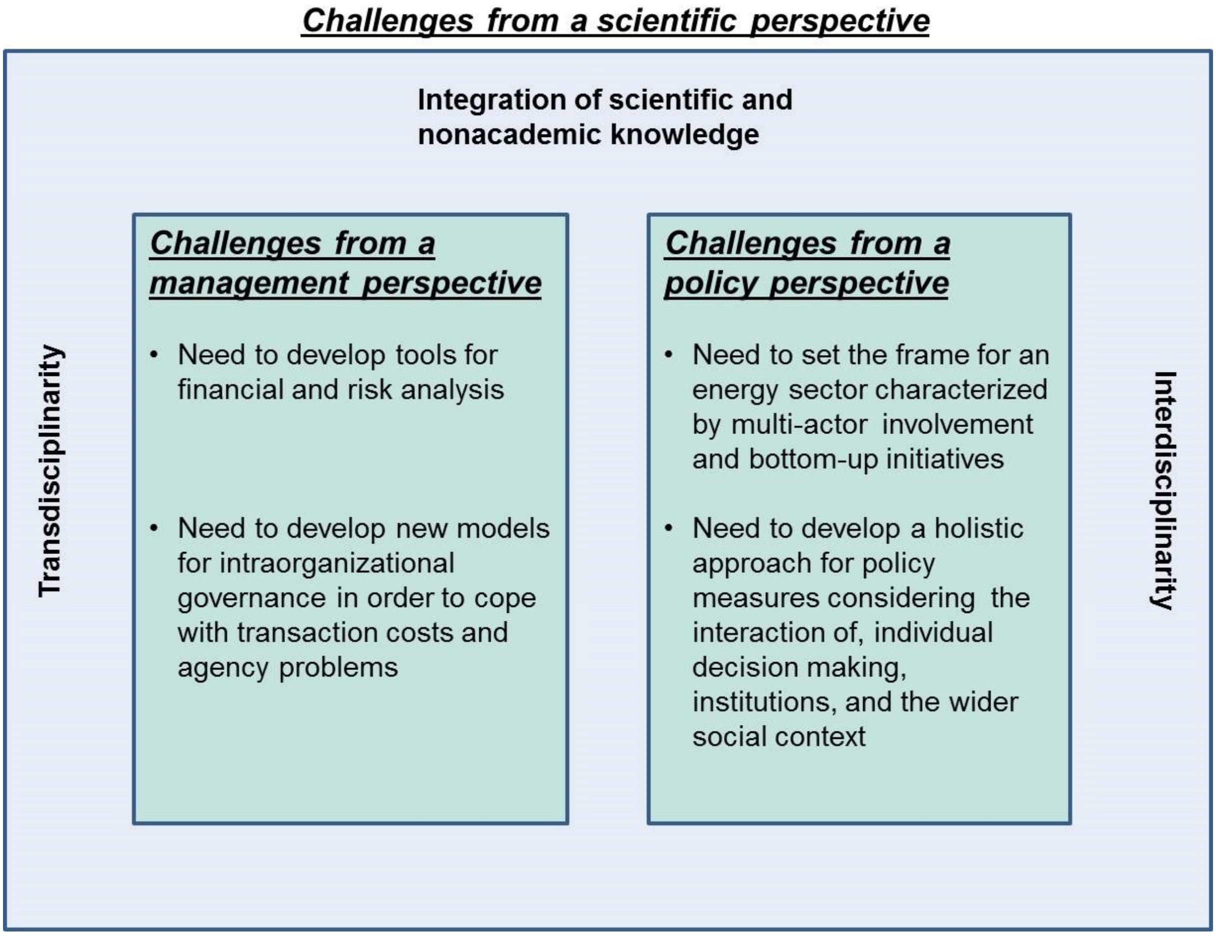

Fig.1.1.: Summary of topics and challenges guiding the further course of this thesis. (Source: author's design).

1.2. Research purpose

This thesis aims at contributing to the discussion on the above-mentioned challenges. While the focus is on analyzing challenges from a managerial and policy perspective, questions regarding transdisciplinarity will be tackled implicitly as some of the research included in this thesis was realized within a transdisciplinary project where the integration of nonacademia actors was a defining characteristic of the conducted research. Hence, some elements of this thesis will serve to illustrate how the collaboration with actors from practice can be realized to explore synergies.

Furthermore, this thesis as a whole provides insights and contributes to the literature on the importance of interconnected human–technology–environment systems. This link between the mentioned domains is fundamental to understand the dynamics of transition processes such as the "Energiewende" (Pahl-Wostl 2007). In this regard, the analysis of this thesis contributes to the assessment of actors involved in the con-

text of the “Energiewende” and aims to draw a link between the characteristics of involved actors, used technologies, and institutional settings.
Furthermore, particular attention is drawn to the human–institution link where the institution defines the organizational environment of human activity. Here, the contribution of this thesis is on intraorganizational and superordinate governance questions, such as of the influence of the institutional setting on the involved actor’s behavior as well as on the question of the implications of the human and technical characteristics of an exchange for the institutional design (see for fundamental questions of the new institutional economics literature e.g., Coase 1937; Williamson 1979/ 2000). This analysis is complemented by a focus on the determinants of human decision making and the implications of findings from this domain for the design of political measures.
According to the described aims, four questions guide the further course of this thesis:

1. Which group(s) of actors is (are) characteristic for the “Energiewende”?
2. What implications do the socioeconomic, technological, and environmental characteristics of actors, processes, and organizational forms in the context of the “Energiewende” have for the management of renewable energy infrastructures?
3. What implications do the socioeconomic, technological, and environmental characteristics of actors, processes, and organizational forms involved in the sustainable transition of the energy sector have for policy?
4. How can inter- and transdisciplinary research methods be included into research in the context of the “Energiewende”?

As some of these questions are interrelated, most of the time, the essays presented will tackle several questions likewise so that at the end, this thesis will present an overall picture with answers to questions related to the sustainable transition of the German energy sector from a managerial, policy, and scientific perspective.

1.3. Structure of the thesis, methodology, and contribution of the essays

This thesis consists, besides the introduction and a final chapter with concluding remarks, of six essays. All essays are based on research that the author conducted within two research projects with one project being a transdisciplinary research project particularly focusing on management aspects of decentralized renewable energy infrastructures and the other being a basic research project focusing on the implications of insights from behavioral economics on policy and governance against the background of the transformation of the energy sector. According to this general overview, the first four papers included in this thesis are the result of the first project, dealing mainly with challenges from a business administration perspective and the last two essays focus particularly on the implications of behavioral economics for policy.

The first essay (Chapter 2: Financing renewable energy infrastructures via financial citizen participation – the case of Germany) provides a meta-analysis on actors in the renewable energy sector and emphasizes the particular role of citizen investors. In this regard, citizen-investor's motivations to enter the market, relevant business models with strengths and disadvantages, and the nexus of individual motivations–underlying technology–organizational form are analyzed. Hence, this review will provide the basis for the following essays as it illustrates the main challenges that arise for citizens as investors as well as for policy as regulative body from the entrance of private individuals in the renewable energy sector.

The second essay (Chapter 3: Energy cooperatives in Germany – growth of energy cooperatives and an analysis from a new institutional economics perspective) addresses the question of intraorganizational governance. Starting with empirical insights on the growth of energy cooperatives in Germany that show particular dynamics of the cooperative business model in the solar energy sector, this essay uses the analytical framework of new institutional economics and conducts a theoretical analysis of transaction costs within cooperatives to explain why solar energy cooperatives are more frequent than cooperatives in other branches of the renewable energy sector. By doing so, this essay not only contributes to the literature on applications of transaction costs economics in the renewable energy sector (e.g., Berry 1995; Altman et al. 2007) and on cooperative businesses (e.g., Bonus 1986; Sykuta and Cook 2001; Chaddad 2012) but also gives recommendations for actors from practice such as citizen investors and project developers which organizational form is most suited for a specific technology.

The third essay (Chapter 4: A microeconomic analysis of decentralized small scale biomass based CHP plants – the case of Germany) introduces a tool to assess a project's financial viability. Hence, this chapter contributes literature on project management tools that facilitate project evaluation and operational control of renewable energy infrastructures (e.g., Walla and Schneeberger 2008; Baños 2011) and therefore can serve as a key factor to promote the further deployment of renewable energy projects. Besides the contribution to the literature on management tools, this essay also tackles the aspect of transdisciplinarity as the concept of the paper was evolved by strongly considering the needs from practice for a standardized tool for project evaluation. In addition, nonacademia actors provided the basis for the numerical example as the numerical example relies on a database on crop characteristics and technical data to which project managers who want to analyze bioenergy projects can resort.

The fourth essay (Chapter 5: Economic risk analysis of decentralized renewable energy infrastructures – A Monte Carlo Simulation Approach) ties closely to the third essay. The risk management tool presented here is essential for the realization of renewable energy projects as a sound risk management is required to display the project's viability to investors and debt repayment capability to lenders. Accordingly, this essay contributes to the literature on risk management of renewable energy projects (e.g., del Caño and de la Cruz 2002; Jackson 2010) and eliminates disadvantages of established risk assessment approaches such as sensitivity analysis (e.g., Borgonovo et al. 2010). In addition, this essay is the paper that respects the most the idea of transdisciplinarity as actors from nonacademia were directly involved in various stages of the conducted research. First, the requirement for a risk management tool that can vary several parameters simultaneously was identified with stakeholders in meetings that aimed at developing decentralized energy projects within the research project "RePro – Ressourcen vom Land". In addition, the input parameters for the numerical example were identified in further meetings with stakeholders at the local level.

The fifth essay (Chapter 6: Nudging as a new "soft" tool in environmental policy – An analysis based on insights from cognitive and social psychology) turns the perspective from the managerial level to the policy domain. In detail, the meta-analysis presented in this chapter provides a first step in a fundamental study of human decision-making as the starting point for policy makers to design policy measures. In the further course, the findings on cognitive processes are used to expand the established policy toolset as the findings show that traditional methods such as monetary incentives are not always effective. Hence, this paper addresses the question of challenges from a governance perspective and contributes to the literature on policy tools in the light of newer findings from behavioral economics and cognitive sciences (e.g., van Den Bergh et al. 2000; Shogren 2002; Shogren et al. 2010; Sunstein and Reisch 2013).

The sixth essay (Chapter 7: Public private partnerships, incomplete contracts, and distributional fairness – when payments matter!) also deals with challenges from a policy perspective. Here, a theoretical microeconomic analysis is conducted to provide insights on governance questions in the context of public private partnerships. In detail, this chapter extends the literature on the allocation of ownership rights and investment incentives in a public private partnership setting (e.g., Shleifer 1998; Hart 2003; Schönfeld 2011) by including insights from behavioral economics on preferences for distributional fairness (e.g., Fehr and Schmidt 1999). These findings are of particular interest as developments in the renewable energy sector (see section 1.1.1. and the essay on citizen participation (section 2)) provide a rationale for the relevance of such preferences. Therefore, the developed model allows a more holistic perspective and analysis of governance questions in the context of renewable energy deployment.

Finally, the paper ends with concluding remarks that synthesize the findings of the individual papers and analyze the findings from a wider perspective. In addition, the final chapter also provides an outlook on further research.

1.4. Literature

Abdala, M.A. (2008): Governance of competitive transmission investment in weak institutional systems. In: *Energy Economics*, 30 (4), 1306-1320.

Agrell, P.J./ Bogetoft, P./ Mikkers, M. (2013): Smart-grid investments, regulation and organization. In: *Energy Policy*, 52, 656-666.

Alexander, C./ Ivanic, R./ Rosch, S./ Tyner, W./ Wu, S.Y./ Yoder, J.R. (2012): Contract theory and implications for perennial energy crop contracting. In: *Energy Economics*, 34 (4), 970-979.

Altman, I.J./ Sanders, D.R./ Boessen, C.R. (2007): Applying transaction cost economics: A note on biomass supply chains. In: *Journal of Agribusiness*, 25 (1), 107-114.

Arnold, U./ Yildiz, Ö. (2015): Economic risk analysis of decentralized renewable energy infrastructures – A Monte Carlo Simulation approach. In: Renewable Energy, 77, 227-239.

Baños, R./ Manzano-Agugliaro, F./ Montoya, F.G./ Gil, C./ Alcayde, A./ Gómez, J. (2011): Optimization methods applied to renewable and sustainable energy: A review. In: *Renewable and Sustainable Energy Reviews*, 15 (4), 1753-1766.

Berry, D. (1995): You've got to pay to play: Photovoltaics and transaction costs. In: *The Electricity Journal*, 8 (2), 42-49.

Böhringer, C./ Rutherford, T.F./ Tol, R.S. (2009): The EU 20/20/2020 targets: An overview of the EMF22 assessment. In: *Energy economics*, 31 (supplement 2), S268-S273.

Bolton, G.E./ Ockenfels, A. (2000): ERC: A Theory of Equity, Reciprocity, and Competition. In: *The American Economic Review*, 90 (1), 166-193.

Bonus, H. (1986): The cooperative association as a business enterprise: a study in the economics of transactions. In: *Journal of Institutional and Theoretical Economics (JITE)/ Zeitschrift für die gesamte Staatswissenschaft*, 142 (2), 310-339.

Borgonovo, E./ Gatti, S./ Peccati, L. (2010): What drives value creation in investment projects? An application of sensitivity analysis to project finance transactions. In: *European Journal of Operational Research*, 205 (1), 227-236.

Böttcher, J. (2009): *Finanzierung von Erneuerbare-Energien-Vorhaben*. Oldenbourg Wissenschaftsverlag, Munich, Germany, 2015.

Bowles, S. (1998): Endogenous preferences: The cultural consequences of markets and other economic institutions. In: *Journal of Economic Literature*, 36 (1), 75-111.

Bowles, S./ Hwang, S. H. (2008): Social preferences and public economics: Mechanism design when social preferences depend on incentives. In: *Journal of Public Economics*, 92 (8), 1811-1820.

Bowles, S./ Polanía-Reyes, S. (2012): Economic incentives and social preferences: substitutes or complements?. In: *Journal of Economic Literature*, 50 (2), 368-425.

Buchholz, W./ Peters, W. (2008): Equal sacrifice and fair burden-sharing in a public goods economy. In: *International Tax and Public Finance*, 15 (4), 415-429.

Busch, H./ McCormick, K. (2014): Local power: exploring the motivations of mayors and key success factors for local municipalities to go 100% renewable energy. In: *Energy, Sustainability and Society*, 4 (3), 1-15.

Carlsson, F./ Johansson-Stenman, O. (2012): Behavioral economics and environmental policy. In: *Annual Review of Resource Economics*, 4 (1), 75-99.

Chaddad, F. (2012): Advancing the theory of the cooperative organization: The cooperative as a true hybrid. In: *Annals of Public and Cooperative Economics*, 83 (4), 445-461.

Coase, R.H. (1937). The nature of the firm. In: *Economica*, 4 (16), 386-405.

del Caño, A./ de la Cruz, M.P. (2002): Integrated methodology for project risk management. In: *Journal of Construction Engineering and Management*, 128 (6), 473-485.

Dóci, G./ Vasileiadou, E. (2015): “Let′ s do it ourselves” Individual motivations for investing in renewables at community level. In: Renewable and Sustainable Energy Reviews, 49, 41-50.

Enengel, B./ Muhar, A./ Penker, M./ Freyer, B./ Drlik, S./ Ritter, F. (2012): Co-production of knowledge in transdisciplinary doctoral theses on landscape development—an analysis of actor roles and knowledge types in different research phases. In: *Landscape and Urban Planning*, 105 (1), 106-117.

Falk, A. (2003): Homo Oeconomicus versus Homo Reciprocans: Ansätze für ein neues Wirtschaftspolitisches Leitbild?. In: *Perspektiven der Wirtschaftspolitik*, 4 (1), 141-172.

Farrell, L.M. (2003): Principal-agency risk in project finance. In: *International Journal of Project Management*, 21 (8), 547-561.

Fehr, E./ Schmidt, K.M. (1999): A Theory of Fairness, Competition, and Cooperation. In: *The Quarterly Journal of Economics*, 114 (3), 817-868.

Fukuyama, F. (2013): What is governance?. In: *Governance*, 26 (3), 347-368.

Gillingham, K./ Palmer, K. (2014): Bridging the energy efficiency gap: policy insights from economic theory and empirical evidence. In: *Review of Environmental Economics and Policy*, 8 (1), 18-38.

Gintis, H. (2000): Beyond Homo economicus: evidence from experimental economics. In: *Ecological Economics*, 35 (3), 311-322.

Grossman, S.J./ Hart, O.D. (1986): The costs and benefits of ownership: A theory of vertical and lateral integration. In: *Journal of Political Economy*, 94 (4), 691-719.

Gsottbauer, E./ van den Bergh, J.C.J.M. (2011): Environmental policy theory given bounded rationality and other-regarding preferences. In: *Environmental and Resource Economics*, 49 (2), 263-304.

Gowdy, J.M. (2008): Behavioral economics and climate change policy. In: *Journal of Economic Behavior & Organization*, 68 (3), 632-644.

Hart, O.D. (2003): Incomplete contracts and public ownership: Remarks, and an application to public-private partnerships. In: *The Economic Journal*, 113 (486), C69-C76.

Hart, O.D./ Moore, J. (1990): Property Rights and the Nature of the Firm. In: *Journal of Political Economy*, 98 (6), 1119-1158.

Hart, O.D./ Shleifer, A./ Vishny, R.W. (1997): The proper scope of government: theory and an application to prisons. In: *The Quarterly Journal of Economics*, 112 (4), 1126-1161.

Hodgson, G.M. (1998): The approach of institutional economics. In: *Journal of Economic Literature*, 36 (1), 166-192.

Jackson, J. (2010): Promoting energy efficiency investments with risk management decision tools. In: *Energy Policy*, 38 (8), 3865-3873.

Johansson-Stenman, O./ Konow, J. (2010): Fair air: distributive justice and environmental economics. In: *Environmental and Resource Economics*, 46 (2), 147-166.

Kahneman, D. (2003): Maps of Bounded Rationality: Psychology for Behavioral Economics. In: *The American Economic Review*, 93 (5), 1449-1475.

Kahneman, D./ Knetsch, J.L./ Thaler, R.H. (1990): Experimental Tests of the Endowment Effect and the Coase Theorem. In: *The Journal of Political Economy*, 98 (6), 1325-1348.

Kahneman, D./ Tversky, A. (1979): Prospect Theory: An Analysis of Decision under Risk. In: *Econometrica*, 47 (2), 263-292.

Kahneman, D./ Tversky, A. (1982): The psychology of preferences. In: *Scientific American*, 246 (1), 160-173.

Kirby, K.N./ Herrnstein, R.J. (1995): Preference Reversals Due to Myopic Discounting of Delayed Reward. In: *Psychological Science*, 6 (2), 83-89.

Knetsch, J.L./ Sinden, J.A. (1984): Willingness to Pay and Compensation Demanded: Experimental Evidence of an Unexpected Disparity in Measures of Value. In: *The Quarterly Journal of Economics*, 99 (3), 507-521.

Lange, A./ Vogt, C. (2003): Cooperation in international environmental negotiations due to a preference for equity. In: *Journal of Public Economics*, 87 (9), 2049-2067.

Lülfesmann, C. (2002): Central governance or subsidiarity: A property-rights approach to federalism. In: *European Economic Review*, 46 (8), 1379-1397.

Manner, M./ Gowdy, J. (2010): The evolution of social and moral behavior: Evolutionary insights for public policy. In: *Ecological Economics*, 69 (4), 753-761.

Markard, J./ Raven, R./ Truffer, B. (2012): Sustainability transitions: An emerging field of research and its prospects. In: *Research Policy*, 41 (6), 955-967.

Meadowcroft, J. (2009): What about the politics? Sustainable development, transition management, and long term energy transitions. In: *Policy Sciences*, 42 (4), 323-340.

Middlemiss, L./ Parrish, B.D. (2010): Building capacity for low-carbon communities: The role of grassroots initiatives. In: *Energy Policy*, 38 (12), 7559-7566.

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. In: *Water Resources Management*, 21 (1), 49-62.

Ritter, F./ Muhar, A./ Fiebig, M. (2010): Scientific knowledge and experiential knowledge in a transdisciplinary dialogue on summer mountain tourism and climate change. In: GAIA – Ecological Perspectives for Science and Society. 19 (3), 194-203.

Rogers, J.C./ Simmons, E.A./ Convery, I./ Weatherall, A. (2008): Public perceptions of opportunities for community-based renewable energy projects. In: *Energy Policy*, 36 (11), 4217-4226.

Rommel, J. (2015): *Institutions, behavior, and the environment – an experimental approach*. Dissertation thesis assigned the URN (urn:nbn:de:kobv:11-100227956), Humboldt-Universität zu Berlin, Berlin, Germany, 2015.

Schönfeld, F. (2011): *Optimales Investitionsverhalten und Verfügungsrechte in Public Private Partnerships*. Nomos Verlag, Baden-Baden, Germany, 2011.

Seyfang, G./ Smith, A. (2007): Grassroots innovations for sustainable development: Towards a new research and policy agenda. In: *Environmental Politics*, 16 (4), 584-603.

Shleifer, A. (1998): State versus private ownership. In: *Journal of Economic Perspectives*, 12 (4), 133-150.

Shogren, J.F. (2002): A behavioral mindset on environment policy. In: *Journal of Socio-Economics*, 31 (4), 355-369.

Shogren, J.F./ Parkhurst, G.M./ Banerjee, P. (2010): Two cheers and a qualm for behavioral environmental economics. In: *Environmental and Resource Economics*, 46 (2), 235-247.

Simon, H.A. (1955): A Behavioral Model of Rational Choice. In: *The Quarterly Journal of Economics*, 69 (1), 99-118.

Streich, P.A./ Levy, J.S. (2007): Time Horizons, Discounting, and Intertemporal Choice. In: *Journal of Conflict Resolution*, 51 (2), 199-226.

Sunstein, C.R./ Reisch, L.A. (2013): Green by default. In: *Kyklos*, 66 (3), 398-402.

Sykuta, M.E./ Cook, M.L. (2001): A new institutional economics approach to contracts and cooperatives. In: *American Journal of Agricultural Economics*, 83 (5), 1273-1279.

van Den Bergh, J.C.J.M./ Ferrer-i-Carbonell, A./ Munda, G. (2000). Alternative models of individual behaviour and implications for environmental policy. In: *Ecological Economics*, 32 (1), 43-61.

von Hirschhausen, C. (2014). The German "Energiewende" – An Introduction. In: *Economics of Energy & Environmental Policy*, 3 (2), 1-12.

Walker, G./ Devine-Wright, P. (2008): Community renewable energy: What should it mean?. In: *Energy Policy*, 36 (2), 497-500.

Walker, G./ Hunter, S./ Devine-Wright, P./ Evans, B./ Fay, H. (2007): Harnessing community energies: explaining and evaluating community-based localism in renewable energy policy in the UK. In: *Global Environmental Politics*, 7 (2), 64-82.

Walla, C./ Schneeberger, W. (2008): The optimal size for biogas plants. In: *Biomass and Bioenergy*, 32 (6), 551-557.

Weber, E.U. (2013): Doing the Right thing Willingly – Using the Insights of Behavioral Decision Research for Better Environmental Decisions. In: Shafir, E. [ed.]: The Behavioral Foundations of Public Policy. Princeton University Press, Princeton, NJ, 2013, pp. 380-397.

Weimann, J. (2015): Die Rolle von Verhaltensökonomik und experimenteller Forschung in Wirtschaftswissenschaft und Politikberatung. In: *Perspektiven der Wirtschaftspolitik*, 16 (3), 231-252.

Williamson, O.E. (1979): Transaction-cost economics: the governance of contractual relations. In: *Journal of Law and Economics*, 22 (2), 233-261.

Williamson, O.E. (1985): *The economic intstitutions of capitalism*. The Free Press, New York, NY, 1985.

Williamson, O.E. (2000): The new institutional economics: taking stock, looking ahead. In: *Journal of Economic Literature*, 38 (3), 595-613.

Yildiz, Ö./ Rommel, J./ Debor, S./ Holstenkamp, L./ Mey, F./ Müller, J.R./ Radtke, J./ Rognli, J. (2015): Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda. In: *Energy Research & Social Science*, 6, 59-73.

Zarri, L. (2010): Behavioral economics has two ‘souls’: Do they both depart from economic rationality?. In: *Journal of Socio-Economics*, 39 (5), 562-567.

Zoellner, J./ Rau, I./ Schweizer-Ries, P. (2011): Beteiligungsprozesse und Entwicklungschancen für Kommunen und Regionen. In: *Ökologisches Wirtschaften*, 26 (3), 25-27.

Chapter 2: Financing renewable energy infrastructures via financial citizen participation – the case of Germany

by Özgür Yildiz

Technische Universität Berlin

Department of Economic Policy and Environmental Economics

Journal article[6] published as:

Yildiz, Ö. (2014): Financing renewable energy infrastructures via financial citizen participation – The case of Germany. In: *Renewable Energy*, 68, 677-685. http://dx.doi.org/10.1016/j.renene.2014.02.038

Abstract

Financing decentralized renewable energy infrastructures in Germany is a complex issue due to the fact that public authorities lack the needed capital and institutional private investors are generally averse to restraints such as high transaction costs and risk-return-concerns. Consequently, alternative financing concepts must be developed to keep the energy transition going. An approach that has recently gained attention in Germany is the concept of financial citizen participation. The concept entails that private individuals contribute to the realization of infrastructure projects by investing in renewable energy projects via various business models and financing concepts.

This article illustrates empirical results on the relevance of financial citizen participation within the German renewable energy sector, briefly reviews the technical, political and legal framework that led to the significant development in the field of financial citizen participation and analyzes different business models and citizen participation schemes from Germany with a particular focus on so called energy cooperatives and closed-end funds.

[6] The style of the original paper was adapted in order to fit the formal style guidelines of this thesis. References within the text to other sections were also adapted in order to correspond with the denotation of this thesis. The appendix section of the original paper can be found at the end of this chapter.

Keywords

Renewable energy finance; energy cooperatives; citizen participation; closed-end funds; business models

Acknowledgements

First of all, the author would like to thank Dr. Nadine Wittmann (TU Berlin – Department of Economic Policy and Environmental Economics) for valuable comments on the paper. In addition, the author would like to thank the German Federal Department of Education and Research (BMBF) for the funding of his research. This research was undertaken within the research project "RePro – Ressourcen vom Land" (support code: 033L008E) and was supported within BMBF-Funding Measure "Sustainable Land Management". The author would also like to thank the Volkswagen Foundation for the funding of his actual research on behavioral economics within the energy sector.

Finally, the author would also like to thank the editorial board, Prof. A.A.M. Sayigh, Prof. David Elliott as well as the anonymous reviewers for valuable comments on the paper and Alexander C. Pusch (successful publishing) for language-editing.

List of abbreviations in chapter 2

AEE	Agentur für Erneuerbare Energien/ German Renewable Energy Agency
BGBl	Bundesgesetzblatt/ Federal Law Gazette
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit/ Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
DENA	Deutsche Energie-Agentur/ German Energy Agency
DGRV	Deutscher Genossenschafts- und Raiffeisenverband e.V./ German Cooperative and Raiffeisen Confederation
EEG	Erneuerbare-Energien-Gesetz/ Renewable Energies Act
eG	eingetragene Genossenschaft/ registered cooperative
EU	Europäische Union/ European Union
FIT	feed-in tariff
GbR	Gesellschaft bürgerlichen Rechts/ partnership under the Civil Code
GmbH	Gesellschaft mit beschränkter Haftung/ limited liabilty company
GmbH & Co. KG	limited partnership with a limited liability company as general partner
KfW	Kreditanstalt für Wiederaufbau/ Reconstruction Loan Corporation
kWh	Kilowattstunde(n)/ kilowatt hour(s)
kWp	Kilowatt Peak/ kilowatt peak
RET	renewable energy technology/ renewable energy technologies
StBa	Statistisches Bundesamt/ Federal Statistical Office
VGF	Verband Geschlossene Fonds e.V./ Association of Closed-End Investment Companies

2.1. Introduction

With the Energy and Climate Change Package presented in 2008, the European Commission introduced various measures to mitigate the consequences of climate change. Among these instruments, the Directive for the Promotion of Energy from Renewable Sources (Directive 2009/28/EC) set mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy of at least 20% by the year 2020 (EU 2009; Jäger-Waldau et al. 2011). The German government took up this target and made it national law with the so called Erneuerbare-Energien-Gesetz (EEG, Renewable Energies Act) which states targets to increase the share of renewable energy sources in electricity supply to at least 35% by the year 2020 and to continuously increase that share thereafter to 80% in 2050 (BGBl 2011).

Currently, renewable energy technologies (RETs) have been seeing a considerable development in Germany. According to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)), the share of renewable energy in gross energy supply increased from 20.5% in 2011 to 22.9% in 2012. The total electricity generation from renewable energy sources amounts to 136 billion kilowatt hours (kWh) with wind energy having a share of 33.8%, bioenergy a share of 30% (considering all possible physical conditions of biogenic fuels), solar energy a share of 20.6% and hydroelectric power production a share of 15.6% of total renewable energy production (BMU 2013).

Although these statistics illustrate a significant development in the right direction and a growing importance of renewable energy in Germany, recent insights on the issue show that the dynamics are slowing down mainly due to changes in government policy since 2010 (e.g. a significant reduction of promotion programs for investments in solar energy in 2012). In order to continue with the energy transition and achieve the postulated goals, investments in several spheres such as centralized infrastructures (e.g. offshore wind parks), decentralized infrastructures (e.g. small scale biogas based combined heat and power plants) or power grids (e.g. transport lines from offshore wind parks in the north to industrial centers in the Rhine area and in the south) are necessary. Appraisements for the investment amount required based on data attained from the Federal Statistical Office (Statistisches Bundesamt (StBa)) and German Energy Agency (Deutsche Energie-Agentur (DENA)) vary from 17 to 19 billion Euros per year until 2020 for heat and electricity production infrastructures plus additional investments of about two billion Euros per year for local distribution grids and about four billion Euros per year for interregional transmission grids until 2020. The estimated amount is significantly higher when one considers investments in energy efficiency (Blazejczak et al. 2013).

Besides this high required investment amount being an obstacle in and of itself, investments in renewable energy technologies are impeded by several financial restrictions such as high transaction costs and under investment problems resulting from institutional constraints such as asset specificity and so called lock-in effects which generally result from investments in long-term capital assets and describe scenarios where high switching costs for system changes lead to under investment (e.g. the so called “carbon lock-in” where industrial economies have become “locked” into fossil energy systems through a path-dependent process driven by technological and institutional increasing returns to scale) (e.g. Finon 2006; Unruh 2000). Further financial impediments such as low equity return rates considering the risk that comes with investments in RETs aggravate the financing framework for RETs. Especially newly classified technologies are confronted with this obstacle, as the chances of success and potential for profit are difficult to assess for external financiers who often lack the relevant information and knowledge to conduct adequate project risk assessment (e.g. Kemfert and Schäfer 2012; Masini and Menichetti 2012).

As a response to these restrictions, different business models in Germany aim to incorporate citizens within the financing of RETs. In the following, this paper will introduce different business models for citizen participation and explain their characteristics. Therefore, it is structured as follows. The next section provides a general description of financial citizen participation, gives empirical insight on the relevance of citizen participation in investment within the German renewable energy sector, and briefly discusses factors fostering the development of financial participation schemes for citizens. Section 2.3. provides an overview on different business models for financial citizen participation and discusses pros and cons of these business models from an investor's point of view. Finally, Section 2.4. is comprised of concluding remarks and opportunities for further research.

2.2. Financing renewable energy and citizen participation in Germany

Although the literature dealing with financing issues in the renewable energy sector is vast and covers a variety of topics, e.g. the analysis of different financing concepts (Mills and Taylor 1994; Derrick 1998), the characteristics of specific institutional investors (Wüstenhagen and Teppo 2006; Moore and Wüstenhagen 2004) or an investor’s decision process (Wüstenhagen and Menichetti 2012), approaches to assess the cost of capital for investments in RETs (Sadorsky 2012) or financial barriers and policy instruments to induce investments in RETs (Painuly 2001) the literature on citizen participation in the financing of renewably energy infrastructures is sparse considering its empirical importance. Additionally, it is often limited to the analysis of fragments within the vast field of citizen participation (Enzensberger et al. 2003a).

The few existing definitions for the term of citizen participation within the context of financing renewable energy infrastructures start from the literature for citizen participation as a device for public authorities to commit citizens in decision-making issues in general and state various characteristics of financial citizen participation. According to these, citizen participation schemes cover all kinds of organizational and financial structures that primarily address the residents of a territorially defined reference framework (e.g. local, municipality, regional or national administration units) and aim to allow for participation and co-determination in public affairs (e.g. energy supply). Another fundamental attribute is a certain, undefined degree of public welfare considerations within the investment decision of participants so that the financial return is not the sole criteria for the relevant participants to evaluate an investment (Holstenkamp and Degenhart 2013).

A second approach to defining citizen ownership (also referred to as citizen energy) distinguishes in citizen participation in a broader and in a narrower sense. Hence, citizen participation in a narrower sense can be identified by the following criteria from other forms of organization for energy projects:

- The group of actors consists of private individuals, individual agricultural enterprises or legal entities (except for large corporations and conglomerates) that invest individually or jointly in renewable energy projects.
- The form of participation is a financial contribution by equity, which is equipped with voting and control rights, so that a control of the projects by the citizens is possible.
- A minimum of 50 % of the voting rights are held by the citizens.

- The investing members of the enterprise come from or are located in a geographically defined area that is the origin of identity formation processes among the involved citizens.

A broader definition is reached by considering that in practice other forms of citizen participation exist. This applies in particular to the participation rate (minority interests), the extent of voting and control rights and the principle of regionalism (trend:research Institut and Leuphana Universität Lüneburg 2013).

According to this definition, empirical insight on ownership structures of existing renewable energy infrastructures (excluding offshore wind, geothermal energy and pumped storage hydro power stations) reveals that citizen participation schemes in a narrower sense account for 34.4 % and citizen participation schemes in a broader sense as defined above for approximately 47 % of the installed renewable energy capacity in Germany in 2012. Remaining shares are divided among institutional and strategic investors (41.5 %) and energy suppliers (12.5 %) (trend:research Institut and Leuphana Universität Lüneburg 2013; see figure 2.1. (**Fig. 2.1.**) for an illustration).[7]

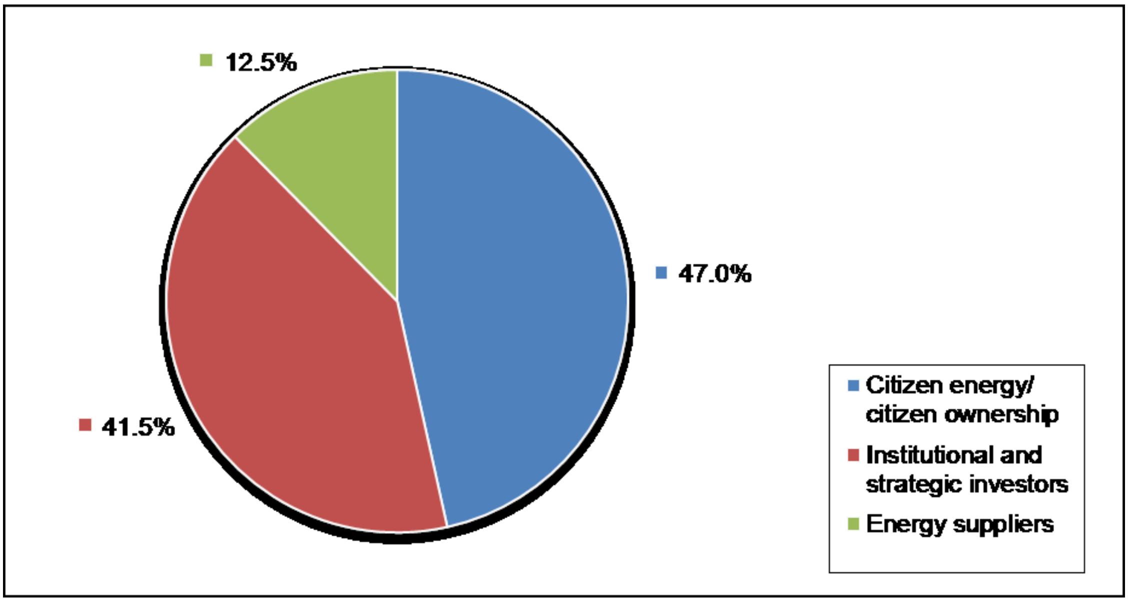

Fig. 2.1.: Ownership shares (in percent) of the total installed renewable energy capacity in Germany in 2012.

(Source: Author's design; based on trend:research Institut and Leuphana Universität Lüneburg 2013).

[7] For a detailed description of all actors represented in **Fig. 2.1.**, see appendix to chapter 2.

A more in-depth analysis reveals that citizen participation and ownership schemes are of particular importance in decentralized renewable energy infrastructures and in the context of solar and onshore wind energy. For solar energy, 48 % of the installed capacity is owned by citizens which are the second largest group behind institutional and strategic investors with a share of 48.5 % of the installed capacity. Well established actors in the energy sector such as local or national energy supply companies are only marginally committed in solar energy. They account for a mere 3.5 % of the installed capacity in Germany. The empirical findings for onshore wind energy are similar, with the difference that citizen's share is even more significant and citizens are consequently the group with the highest share of the installed capacity. Here, 50.4 % of the installed capacity is owned by the group of citizens followed by institutional and strategic investors who own 39.4 % and the group of energy suppliers with a share of 10.2 %. The same results are reached when analyzing the bioenergy sector. Here, citizen ownership accounts for a share 42.2 % of the installed capacity followed by institutional and strategic investors (36.1 %) and energy suppliers (21.7 %). In contrast to these branches, citizens are less committed in other RET domains, especially in those with high investment requirements (e.g. hydroelectric power production, offshore wind power) (trend:research Institut and Leuphana Universität Lüneburg 2013). Figure 2.2. (**Fig. 2.2.**) subsumes the empirical results and illustrates the share of citizen ownership on the installed capacity subdivided by technology.

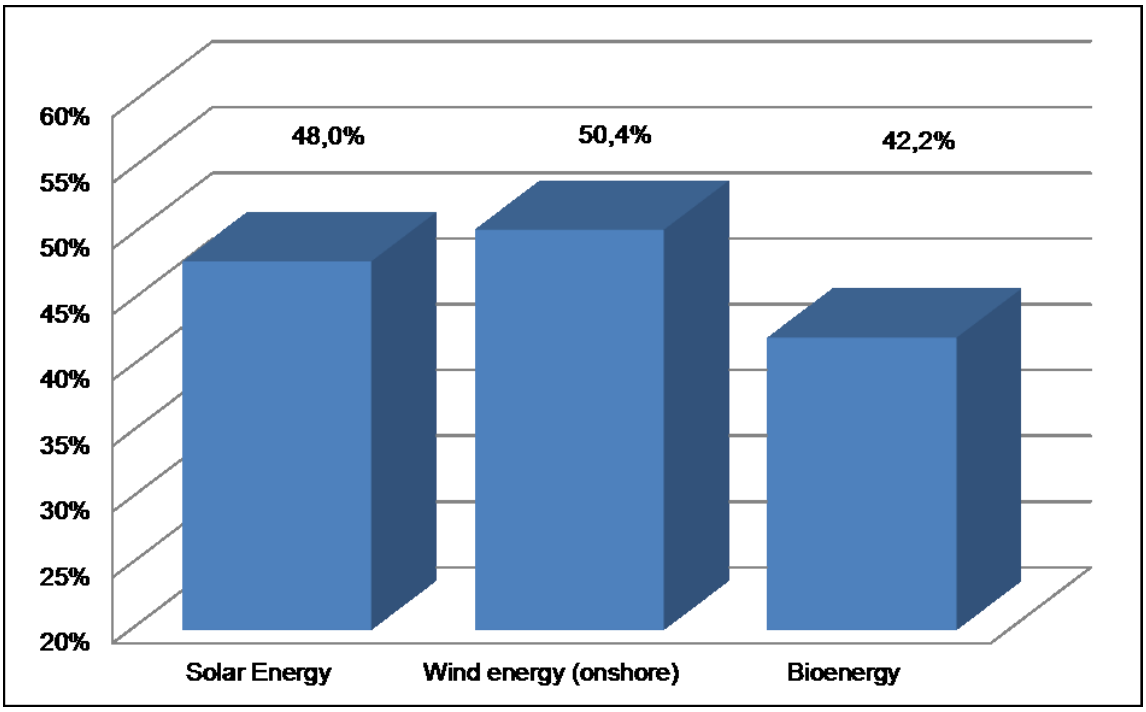

Fig. 2.2.: Share of citizen ownership of the installed renewable energy capacity in Germany, subdivided by technology.
(Source: Author's design, based on trend:research Institut and Leuphana Universität Lüneburg 2013).

Regarding investment volumes, citizens also contribute a large share. However, institutional and strategic investors are clearly the most significant contributors concerning this financial characteristic. Here, the group of institutional and strategic investors contributes about 59.2 % to total investments in renewable energy in Germany in 2012.[8] Citizens account for a share of 30.6 % of total investments in Germany in renewable electricity which corresponds to an amount of approximately 5 Billion Euro. Energy suppliers contributed 10.2 % to total investments in renewable electricity production in Germany in 2012 (trend:research Institut and Leuphana Universität Lüneburg 2013).
Regarding this discrepancy between ownership shares and investment volumes, a remark has to be made in order to explain this considerable difference. The question of the operationalization of the importance of citizens for renewable energy deployment can be addressed in several ways. The mentioned share of citizen ownership of the installed renewable energy capacity addresses a physical dimension of renewable energy in Germany. It is regularly used for operationalization of market shares of

[8] The investment volumes consider only renewable electricity production. As for the analysis of ownership shares, it does not include data on offshore wind energy, geothermal energy and pumped storage hydro power stations.

respective actors within the energy sector as the data for this attribute is easy to collect due to the fact that concerned net operators are obligated to gather information on connected plants to their grid. In contrast to this, investment volumes address a financial dimension of citizen participation. The assessment of investment volumes per year is more of a projection using assumptions about average investment cost per kilowatt per technology given an installed capacity. It is methodically not accurate to project the share of the installed capacity to the share of investment. This can be demonstrated with a simple example: a plant with an ownership structure where citizens contributed 51 % of the equity will be classified as citizen ownership according to the empirical investigation on ownership shares of installed capacity. However, this clearly does not imply that citizens invested 100 % of the equity for this respective plant (see also trend:research Institut and Leuphana Universität Lüneburg 2013 for a more detailed discussion of the data set and methodology). Nonetheless, the presented data in either way reveals a substantial contribution of citizens for renewable energy deployment and finance, particularly for solar energy, onshore wind power and bioenergy.

Reasons for this large contribution of citizens as investors within certain technologies of the renewable energy sector lay within financial characteristics, technology specific aspects and the institutional framework of renewable energy deployment in Germany.

As already mentioned, RETs are confronted with several financial constraints such as high transaction costs or comparatively low equity return rates. These impediments particularly affect decentralized, small-scale renewable energy infrastructures (see section 2.1.). Consequently, decentralized projects are financially unappealing for large energy companies operating nation- or worldwide or investment funds which have to offer higher equity return rates to their shareholders and investors than the regularly offered 4-6 % yield expectations of decentralized renewable energy infrastructures in Germany. Besides these financial aspects, the aversion of large energy companies towards decentralized infrastructures is further intensified due to a general lack of experience with small projects. In addition, the underlying bias is fueled by the negative competitive impact of such decentralized projects on the economic efficiency of existing fossil peak plants owned by nationwide operating energy suppliers. Hence, especially decentralized, small scale infrastructures are affected by a lack of investment. However, local population investing in citizen participation schemes alleviates this situation since the offered yield expectations are generally adequate for this group and the financing additionally provides the possibility to play an active part in local energy policy and planning. Further economic aspects that foster citizen participation within financing renewable energy infrastructures are comparatively low investment volumes that can be jointly raised by local population or the German feed-in tariff (FIT) system fixed in the Renewable Energies Act (EEG) which to a certain degree provides security for citizens as investors and makes it easier for them to assess a project's earnings (Boenigk et al. 2013).

From a technical point of view, characteristics of some RETs are similarly favorable to citizen participation schemes: photovoltaics are particularly attractive because of their modularity, simplicity, high reliability, low maintenance requirements and short lead times. Consequently, these attributes qualify photovoltaics for a variety of fields of application such as solar parks, a part of the energy-mix of decentralized energy supply for rural communities or solar home systems. Although these favorable characteristics should account for every investor regardless of the respective institutional background, the low level of activity by energy supply companies on the field of solar energy can also be traced to technical and resource-based characteristics. Since solar energy is a fluctuant technology, energy supply companies are not able to provide base load with solar energy which consequently makes investments in this technology unappealing. Furthermore, investments in solar energy would, to a certain extent, imply in-house competition since the operated solar plants reduce the hours during which energy supply companies can run their existing fossil peak plants (Oliver and Jackson 1999). The favorable attributes of solar energy can also be assigned to the case of onshore wind energy where the simplicity of the power generation process, the high reliability of the underlying technology and the availability of technical service providers facilitates the use of onshore wind energy for citizens in Germany (Harborne and Hendry 2009).

Besides these financial and technical aspects of RETs, the institutional and political framework has offered and still provides several incentives that support the development of citizen–investor-owned schemes in Germany. First, the legal framework allows different business models for financial citizen participation within the renewable energy sector (see next section for a detailed description). Second, as mentioned before, the German FIT-system serves investors with a stable framework and guaranteed revenues for energy produced. Especially for the case of photovoltaics, the framework has been favorable until 2012 since the FIT-system granted the highest tariffs to electricity produced by photovoltaic devices. This strong incentive set by the German FIT-system was accompanied by further measures e.g. the so called '100,000 Solar Roofs Initiative' which offered loans at low interest rates for citizens for solar energy installations or other loan programs by the state-owned German development bank (Kreditanstalt für Wiederaufbau (KfW)) so that the deployment of this technology has increased significantly to become the RET with the highest installed capacity, on par with onshore wind power (Grau et al. 2012).

Finally, starting from the formation of cooperatives to ensure energy supply in rural areas by the end of the 19th century, Germans have a long tradition in participating in energy and regional development issues in general be it financially or ideologically e.g. in the anti-nuclear-movement (Toke et al. 2008) so that the significant financial citizen participation within the German renewable energy sector is well-founded. The next section proceeds to the main issue of this paper and presents and discusses business models for financial citizen participation.

2.3. Business models for financial citizen participation

Generally, citizens who seek to participate financially in a renewable energy project have a variety of possibilities at their disposal. Although the approach to defining citizen participation in the previous section focuses on citizen ownership and equity finance, the following analysis of relevant business models considers a wider perception of the term financial citizen participation since practice shows a multitude of organizational and financial structures where citizens are committed financially to renewable energy projects without explicit rights of co-determination or liability obligations resulting from equity (e.g. mezzanine financing or debt financing as a creditor) or without a focus on the residents of a territorially defined reference framework. However, business models for equity finance are presented first in order to establish a relationship to the empirical results on ownership structures in the German renewable energy sector described in the previous section.

A second preliminary remark concerns the analysis of the business models and difficulties in estimating related investment amounts. If the assessment of total investment amounts is difficult and relies on projections (as mentioned in the previous section), then the assessment of investment amounts related to a specific business model is even more difficult. Consequently, the analysis of the empirical data acquired is not a central aspect of the analysis presented in this section. It rather serves as an illustrative measure, whereas the focus in this section is on business models, their characteristics and their advantages given preferences of investing citizens.

2.3.1. Equity based schemes for financial citizen participation – Business models and discussion

Equity finance is a well-established vehicle for financial citizen participation. Business models vary in their degree of co-determination and in the controlling and voting rights conceded to committed citizens, so that project initiators often need to be conscious of the degree of co-determination intended since this aspect has a decisive influence on any project's manageability.

2.3.1.1. The energy cooperative

The cooperative as an organizational form has a long tradition in Germany as a business model to commit citizens financially to energy projects. By the end of the 19th century, several cooperatives in rural areas were formed with the task to produce energy or build and operate a distribution grid, as larger energy companies did not provide these services because they lacked profitability due to sparse population in rural areas. While the number of cooperatives sank significantly from the middle of the 20th century with its focus on coal, gas and nuclear energy, recent developments towards renewable energies with the associated possibilities for the decentralization of energy production revived the phenomenon of cooperative organization in the energy sector tremendously and led to the resurgence of a variety of forms (Herlinghaus et al. 2008).

Approaches to a systematization of energy cooperatives distinguish between resource based and activity based approaches. According to this, resource based approaches differentiate between photovoltaic, wind energy, bioenergy as well as service and marketing cooperatives. Activity based approaches group energy cooperatives according to their main business field along the value chain in the energy sector, e.g. energy production, energy consumption or energy services. Energy production cooperatives represent associations of local stakeholders (citizens and/ or local companies) that jointly produce and bring to market energy from renewable sources whereas energy consumer cooperatives mainly deal with the purchase and sale of energy from renewable sources to end consumers. Energy service cooperatives are engaged in a variety of activities, e.g. consulting services on energy efficiency issues, production and supply or distribution. Consequently, they often bundle a number of business fields of local companies which operate in the energy sector (Holstenkamp 2012).

As the attempts to define energy cooperatives show, this form of organization is not exclusively a vehicle for financial citizen participation but rather an (organizational) instrument for different stakeholders such as local businesses, farmers/ agricultural holdings, stockbreeders, communal authorities or communal undertakings to realize decentralized energy infrastructures and to take part in the decision-making of local energy policy. Therefore, the assessment of the number of energy cooperatives owned entirely by citizens is difficult to determine, due to the fact that empirical studies only cover the development of energy cooperatives and membership structures in general. However, the analysis of these studies provides some guidance on the importance of financial citizen participation within the field of energy cooperatives.

According to this, a statistical overview at the end of 2012 counts 754 energy cooperatives listed in the cooperative registries whereof 431 are attributed to solar energy and 47 to onshore wind power. Prominent among remaining energy cooperatives are bioenergy cooperatives and service cooperatives not further specified, whereas cooperatives play a zero role as an organizational form for the case of offshore wind power and geothermal energy (Holstenkamp and Müller 2013). Further data by the German Cooperative and Raiffeisen Confederation (Deutscher Genossenschafts- und Raiffeisenverband e.V. (DGRV)) reveal that the 754 energy cooperatives have about 136.000 members, about 125.000 of whom classified as citizens. The remainders are mostly producing and manufacturing companies engaged in wood based bioenergy. Concerning the raised amounts by energy cooperatives in general (including citizens as well as other investors, e.g. producing and manufacturing companies), the 754 registered energy cooperatives in service by the end of 2012 have raised approximately 426 million Euros equity. Considering the total investment including debt capital, the registered energy cooperatives have already invested a total of 1.2 billion Euros in renewable energy.[9] The proportion of equity to total investments shows that energy cooperatives are characterized by a comparatively high equity

[9] The average financial involvement of the cooperative members amounts to 3.125 Euro per member. Multiplied with the number of citizens participating in cooperatives, this leads to an estimated total amount of about 391 Million Euros equity raised by citizens in cooperatives. However, this is only a simplified projection.

ratio. Debt capital stems mainly from cooperative banks or subsidized loans. About half of the borrowed funds originate from cooperative banks. Another third comes from subsidized loans, in particular loans from the state-owned German development bank KfW, which are usually granted by regional development banks or savings banks (DGRV 2013).

The attractiveness of the cooperative as a financing vehicle for citizens can be attributed to several reasons. First of all, financial barriers for an accedence are typically low since most cooperatives demand an amount varying from 50 to 5.000 Euro per (cooperative) share depending on the total investment of the underlying energy project. Although corporate guidelines of cooperatives with a smaller amount per share often demand the buying of multiple shares (often ten or 25) these amounts still remain moderate especially considering the economic potential given the average income and wealth of the German population so that a considerable part of the population can financially participate if interested (Maron and Maron 2012).

Second, and probably the more important reason for choosing a cooperative as an instrument for financial citizen participation is the active role that the members of the cooperative can play within entrepreneurial decision-making processes. Hence, the cooperative is an association comprising persons with a common objective (e.g. supply with energy from renewable resources) whereby each member has a voice in the selection of the board of management and the board of directors, irrespective of his share in the cooperative, and a proportional participation in benefits accruing from the association's activities (Centner 1988). This construction enables participants to play an active part in local energy policy by exercising co-determination within the general assembly and administrative bodies of the cooperative and is of particular interest for groups of investors that want to limit the influence of a single shareholder (e.g. energy suppliers or project developers which operate the facility) on entrepreneurial decision-making since every cooperative member has a single vote. This hinders financially highly committed members to impose their will on the rest of the cooperatives' members.

Finally, other important aspects of cooperatives for their investors are risk considerations and additional institutional support mechanisms provided by the DGRV. Personal liability of participants is generally limited to the capital invested so that members needn't assess the risk for further claims in case of project failure. Furthermore, planned cooperatives are financially screened by auditing and consulting associations of the DGRV in order to support the realization process (Wieg et al. 2011).

Along with these favorable factors, several restraints from a citizen's point of view should be considered. Although the DGRV provides ample support, formal organization costs remain high compared to other legal forms due to the fact that the legal authorization requires a specific report on the planned business and its financial viability (Volz 2010). In addition, individual internal organization costs are significant since the active participation form within a cooperative demands from its participants a certain degree of effort in the form of gathering information on a facility's and management's performance in order control the management in charge. Finally, the decision-making process within a cooperative can lead to the so called influence cost problem which describes situations where cooperative members have to undertake material and immaterial efforts to influence decision-making in pursuit of their own particular interests (Cook 1995).

The following case studies illustrate the above-mentioned findings on energy cooperatives in an exemplary fashion and reveal the close and active form of citizen participation within this business model.

A first example is the municipality of Weissach im Tal in the Federal State of Baden-Württemberg where local citizens in 2008 decided to form a cooperative (Energiegemeinschaft Weissacher Tal eG) to install solar panels and provide local citizens with energy from renewable sources. Today the cooperative has about 240 members signed for approximately 14.000 business shares for a price of 50 Euro apiece. Both the board of directors and the management are carried voluntarily by the mayor of the municipality and local citizens. In total, the energy cooperative "Energiegemeinschaft Weissacher Tal eG" operates ten photovoltaic plants, all of these installed on roofs of municipal buildings and producing approximately 330.000 kilowatt hours (kWh) of electricity per year. This corresponds to a saving of approximately 230 tonnes of CO_2. In addition, cooperative members received an annual return of around four per cent per share in 2012 (AEE 2013; Energiegemeinschaft Weissacher Tal e.G. 2013). Other examples are the energy cooperative "BürgerEnergiegenossenschaft Rotach-Schussen-Argen eG", also in the Federal State of Baden-Württemberg, relying on solar and hydroelectric energy (BürgerEnergiegenossenschaft Rotach-Schussen-Argen eG 2013) and the energy cooperative "Energiegenossenschaft Starkenburg eG" in the Federal State of Hesse with a focus on wind and solar power (Energiegenossenschaft Starkenburg eG 2013). The following table (**Tab. 2.1.**) illustrates the main characteristics of the three case studies presented.

	Energiegemeinschaft Weissacher Tal eG	BürgerEnergiegenos-senschaft Rotach-Schussen-Argen eG	Energiegenossenschaft Starkenburg eG
Underlying Technology	Photovoltaics (10 different projects, installed on local build-ings)	Photovoltaics and hydroelectricity (2 solar projects in-stalled on local build-ings, 1 hydroelectric power station)	Photovoltaics and wind energy (9 solar projects on local buildings, 1 wind turbine on agricultural land)
Installed capacity	358 kWp	49, 4 kWp (solar) 27 kWh (hydroelectric)	608.55 kWp (solar) 2.05 MW (wind)
Energy production in 2012	330000 kWh	29600 kWh (solar) 63400 kWh (hydroelectric power)	288790 kWh (solar, not all disclosed) 4440000 kWh (wind)
Members	240	280	509
Total Shares	14000	1307	not disclosed
Amount per share in Euros	50	100	100 (plus the obligatory disposition of an subor-dinated loan of 1800 Euro)
Annual return in % per share in 2012	4 %	4 %	5 %

Tab. 2.1.: Overview on technical and financial characteristics of three exemplary energy cooperatives in Germany.
(Source: author's design based on AEE 2013; Energiegemeinschaft Weissacher Tal e.G. 2013; Bür-gerEnergiegenossenschaft Rotach-Schussen-Argen eG 2013; Energiegenossenschaft Starkenburg eG 2013).

2.3.1.2. Closed-end funds

Closed-end funds are similar to cooperatives in that they are primarily a vehicle for raising equity capital through a large number of investors. The legal form in Germany to realize closed-end funds within the energy sector is mainly the so called GmbH & Co. KG. This legal entity consists of two different shareholder groups, limited partners that are liable only to the amount of their capital inlaid and a limited liability company as general partner which is in charge of business management. Initiators and general partners are normally corporative actors, e.g. farmers/ agricultural holdings, energy suppliers, plant producers, project developers whereas citizens financially participate as limited partners. Other providers for closed-end funds for renewably energy finance are financial service companies that raise high equity amounts to invest in different projects or regional project initiators that realize single, decentralized projects via closed-end funds (Degenhart and Schomerus 2008).

The only accessible source for indications on the potential of closed-end funds for renewable energy finance are empirical studies by the German association for closed-end funds (Verband Geschlossene Fonds (VGF)) which reveal significant investment in closed-end funds within the energy sector in general. According to these studies, an equity amount of 723.2 Million Euros (372.5 Million Euros of it by the distribution channel of private investors) was raised in 2012 via energy related closed-end funds with an average of about 15.000 investors per fund (VGF 2013). At this juncture, some critical remarks are in order. First, the VGF does not differentiate between renewable and fossil energy investments. Consequently, the category energy sector also includes closed-end funds that invest in fossil energy (e.g. POC Natural Gas 1). However, the number of these funds is small compared to the number of closed-end funds investing in renewable energy. Second, the VGF collects only data on various distribution channels such as private and institutional investors but makes no inquiry on those who participate in these funds so that the exact ascertainment of the allocation of this amount to citizens cannot be determined with the existing data set. Finally and most importantly, the VGF has no data on the numerous local, small scale projects that are financed by citizens with locally restricted closed-end funds in the legal form of a GmbH & Co. KG. Nonetheless, the existing data set from the VGF which illustrates significant investment amounts raised by institutional investors among citizens and other investor groups as well as innumerable examples for local activities in practice indicate a significant importance of closed-end funds in financial citizen participation within the energy sector.

The basic motivation for citizens to participate in renewable energy finance via closed-end funds results from several reasons. Considering liability issues, closed-end funds in the legal form of a GmbH & Co. KG structure offer similar characteristics as a corporation, i.e. none of the partners has full liability in case of project failure. Otherwise, investment projects of this size would generally be too risky for small private investors to undertake. Furthermore, due to their role as limited partners, citizens contributing to renewable energy projects have no impact on entrepreneurial decision-making so that this structure is particularly relevant for citizens that want to invest in RETs while avoiding participation in issues relating to business. From another point of view, the lack of co-determination for limited partners also positively affects the manageability of the entire structure since the full entrepreneurial responsibility for the project is assigned by law to the general partner. And finally, closed-end funds offer fiscal advantages since the company's revenues are treated as income for the respective investors and therefore taxed under the income tax scheme rather than corporate tax schemes. Applying this framework, financial losses during the first years of the project can be offset against other income thereby provoking a deferment of tax payments to later years (Enzensberger et al. 2003b).

However, this business model also brings with it some inconvient aspects, as it is unsuited for citizens that explicitly want to participate in entrepreneurial decision-making processes and seek to exercise control on management. Therefore, decentralized projects initiated by local citizen with the aim of controlling local energy policy tend to choose a cooperative as the form of citizen participation.

Examples from practice that illustrate the findings above should be, according to the specification mentioned in the text, differentiated in two categories: closed-end funds provided by financial services companies as covered in the statistics on closed-end funds by the VGF and as well as decentralized energy projects structured by the legal form of a GmbH & Co. KG and hence financed by closed-end fund schemes.

Financial service companies providing funds are well established firms in the finance sector such as Aquila Capital Concepts, DWS – Deutsche Asset and Wealth Management or KGAL Investment Management (data source see VGF 2013). The number of decentralized projects that aim to incorporate citizens within the financing of renewable energy is even higher. As an example, it may serve to mention so called

“Bürgerwindparks” – closed-end fund based financial citizen participation schemes for wind energy. The “Bürgerwindpark Hollich GmbH & Co. KG” in the farming community of Hollich in the Federal State of North Rhine-Westphalia with 217 citizens as limited partners operates 19 wind turbines with an installed capacity of 29.5 MW and energy production of about 55000000 kWh in 2012. The involved limited partners received an annual return of about 10 % on their investment resulting from earnings of land leasing receipts and energy production (Windpark Hollich GmbH & Co.KG 2013). Another example is the planned “Bürgerwindpark Niebüll GmbH & Co. KG” where about 1000 citizens contribute as limited partners to a wind park with an installed total capacity of 15 MW and an estimated energy production of 61000000 kWh per year after going into service in 2014 (Bürgerwindpark Niebüll GmbH & Co. KG 2013). The following table (**Tab. 2.2.**) summarizes the principal technical and financial characteristics of the case studies.

	Bürgerwindpark Hollich GmbH & Co. KG	Bürgerwindpark Niebüll GmbH & Co. KG
Underlying Technology	Wind (19 wind turbines)	Wind (5 wind turbines)
Installed capacity	varying from 1.5 – 2 MW (29.5 MW total)	3 MW per wind trubine
Energy production in 2012	about 55000000 kWh	61000000 kWh (estimation for 2014)
Members	217	about 1000
Amount per share in Euros	not disclosed	500
Annual return on investment in % in 2012	10 % (resulting from land leasing receipts and energy production)	Plant in construction.

Tab. 2.2.: Overview of the technical and financial characteristics of two exemplary “Bürgerwindpark” projects in Germany.

(Source: author’s design, based on Windpark Hollich GmbH & Co.KG 2013; Bürgerwindpark Niebüll GmbH & Co. KG 2013).

2.3.1.3. Other forms of equity finance

Besides the two presented forms of financial citizen participation, for the sake of completeness one should mention that project initiators also dispose of and use in practice other legal forms to raise equity from citizens and realize RET projects. These forms cover corporate entities, e.g. limited liability companies (so called Gesellschaft mit beschränkter Haftung (GmbH)) or stock corporations as well as companies under private law (so called Gesellschaft bürgerlichen Rechts (GbR)).

Among these forms, the company under private law is of particular interest for citizen participation in small scale infrastructures with comparatively low economic risk. It is characterized by low legal requirements and full liability of its company members. Consequently, this participation scheme comes with high financial risks for citizens and is therefore unsuited for projects with large investment volumes but can be interesting for project initiators with small scale projects, low investment, manageable risks and a preference for active participation of equity investors in entrepreneurial decision-making (Rau and Zoellner 2011). The following two case studies illustrate exemplary participation schemes on the legal basis of a GbR (see also **Tab. 2.3**).

The first example is the project “Bürgersolar Hilchenbach GbR” in the town of Hilchenbach in the Federal State of North Rhine-Westphalia. Here, two solar plants with a total installed capacity of 42 kWp were realized on the roof of communal buildings. 39 citizens contributed financially to the realization by signing shares with a face value of 1000 Euro per share. The annual return on investment projected for 2012 was 5%. Another example is the project “1. BürgerSolar Recklinghausen GbR” in the town of Recklinghausen also in the Federal State of North Rhine-Westphalia where about 80 citizens signed shares of 500 Euros apiece to realize a solar plant with an installed capacity of 75 kWp (EnergieAgentur.NRW 2011).

	Bürgersolar Hilchenbach GbR	1. BürgerSolar Recklinghausen GbR
Underlying Technology	Photovoltaics (2 plants on communal buildings)	Photovoltaics (1 plant on a communal building)
Installed capacity	42 kWp	75 kWp
Energy production in 2012	about 37.000 kWh (Projection)	about 67000 kWh (Projection)
Members	39	82
Amount per share in Euros	1000	500
Annual return on investment in % in 2012	5 % (Projection)	about 8% (Projection)

Tab. 2.3.: Overview of the technical and financial characteristics of two exemplary projects in Germany in the legal form of a GbR.
(source: author's design, based on EnergieAgentur.NRW 2011).

2.3.2. Debt and mezzanine capital based schemes for citizen participation

The extent of debt and mezzanine-financing as a vehicle for citizen participation within renewable energy finance is significantly smaller compared to equity based citizen participation schemes.

For debt finance, corresponding to the nature of this scheme, there is an underlying temporary limited contractual obligation with guaranteed returns. Examples in practice are savings bonds or corporate bonds. Providers of these schemes are often local savings banks in cooperation with local energy suppliers, private banks specialized on ecological and socially responsible topics and investments (e.g. GLS-Bank, Triodos Bank) or project developers. Saver's motivation for savings bonds are often the exclusive desire to invest within the field of renewable energy to save conditions and guaranteed returns whereat savers often do not even know to which specific project they are contributing (GLS Gemeinschaftsbank eG 2013).

Mezzanine-finance is often realized via profit participation rights which are provided mostly by project development companies, e.g. "Prokon" or "juwi renewable IPP", and like savings bonds aim at raising capital from citizens that are interested in renewable energy investments but have no further interest in dealing with entrepreneurial issues or the examination of a specific project. In contrast to savings bonds, returns often partly depend on the performance of the provider and consequently vary within a margin (PROKON Unternehmensgruppe 2013).

2.4. Concluding remarks and implications for further research

The analysis of business models for financial citizen participation within the German renewable energy sector revealed a variety of different schemes that commit citizen to renewable energy finance. These business models on the one hand cover equity financing concepts relevant for small scale, decentralized projects as well as for large scale projects with higher investments with varying individual amounts to be invested and varying dimensions of information, control and co-determination rights. On the other hand, debt and mezzanine-finance schemes where citizens are less opposed to entrepreneurial risks and less committed to a specific project.

Further research within the field of financial citizen participation can be conducted in various ways. First, there are general questions regarding the debt arrangements of business involving citizens in renewable energy finance. An analysis of the capital structure and the institutional background of financial institutions providing debt capital would not only give insight on how existing financial institutions and instruments complement the equity raised by citizens but also help to develop measures and a framework to further promote investments of citizens in renewable energy.

Second, the detailed analysis of the invested amounts discovered a lack of relevant data in general. Besides missing data on business models in the legal form of a GmbH that are also occasionally used within the field of financial citizen participation or data on the amounts raised by other participation forms (e.g. companies under private law, debt and mezzanine capital based schemes), there is no explicit data on the amounts raised via closed-end funds in the legal form of a GmbH & Co. KG, not listed on the capital market and addressed to private investors that want to contribute to a local renewable energy project. However, these business models are predominant within the field of financial citizen participation so that the lack of relevant data here is substantial.

Third, the reluctant response of the public to plans of the Federal Ministry of Economics and Technology and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety to introduce a financial participation scheme for citizens to contribute to transmission grid expansion has pointed to the fact that business models need to be designed with great consideration for the interaction of different preferences of citizens, e.g. the underlying technology and possible by-effects of a specific technology as well as geographical and ideological issues. According to this, future tasks cover among other the assessment of determinants within the decision making process of citizens (e.g. underlying technology, dimension of participation in decision-making, consideration of other determinants such as ideological motives) in order to create suited business models and keep private contribution to renewable energy finance going, even expanding it to other fields such as storage technologies or to involve citizens in projects in order to reduce expected opposition to projects as it is the case for investments in transmission grids.

Besides this analysis of citizens' preferences as investors, it is worthwhile to analyze the effects of policy measures and the legal framework on financial citizen participation. This article conjectured that mechanisms such as the German FIT-system or public measures such as publicly supported loan programs had a decisive impact on the diffusion and expansion of solar energy. This large expansion of solar energy was criticized repeatedly since solar energy is fluctuant (and therefore improper for base load supply) and in general has higher electricity production costs per kWh than other renewable energy technologies so that it is interesting to know how policy measures, the legal and the institutional framework could be modified in order to induce increased citizen participation in fields that are necessary for a successful transition of the energy sector but at the moment not in the focus of citizen finance (e.g. the realization of storage technologies such as pumped storage hydro power stations).

Finally, an analysis of financial citizen participation schemes in other countries could also provide important findings. This analysis can cover the appraisal of business models in different countries, research on the interaction of different political and institutional frameworks with the diffusion of citizen participation schemes as well as research on the transferability of existing business models to countries where citizens are not active in the field of renewable energy or where the deployment of RETs is progressing slowly in general so that the transition towards renewable energy can be further advanced throughout the world.

2.5. Literature

Agentur für Erneuerbare Energien e.V. (AEE) (2013): *Energiekommunen/2011/August – Weissach im Tal*. URL: http://www.kommunal-erneuerbar.de/de/energie-kommunen/2011/august.html (last time accessed 08.10.2015).

Blazejczak, J./ Diekmann, J./ Edler, D./ Kemfert, C./ Neuhoff, K./ Schill, W.P. (2013): Energiewende erfordert hohe Investitionen. In: *DIW-Wochenbericht*, 80 (26), 19-30.

Boenigk, N./ Dannemann, B./ Biehl, J./ Schneider, D./ Simons, K./ Katz. J./ Altegör, T./ Klaaßen, L./ Weller, K. (2013): *Bürgerbeteiligung – Die energiewende gestalten*. Agentur für Erneuerbare Energien (AEE) e.V., Berlin, Germany, 2013. Study also available on the internet at the following address, URL: http://www.kommunal-erneuerbar.de/fileadmin/content/PDF/KOMM-MAG_online.pdf (last time accessed 08.10.2015).

Bundesgesetzblatt (BGBl) (2011): *Gesetz zur Neuregelung des Rechtsrahmens für die Förderung der Stromerzeug ung aus erneuerbaren Energien vom 28. Juli 2011 – Bundesgesetzblatt Jahrgang 2011 Teil I Nr. 42 S. 1634*. Legislative text also available on the internet at the following address, URL: http://www.bgbl.de/xaver/bgbl/start.xav?start=//*[@attr_id=%27bgbl111s1633.pdf%27]#__bgbl__%2F%2F*[%40attr_id%3D%27bgbl111s1634.pdf%27]__1445347531561 (last time accessed 08.10.2015). [Note: In the original paper, a reference is made to the URL: http://www.gesetze-im-internet.de/eeg_2009/BJNR207410008.html. As this link wasn't available anymore, the link has been updated.]

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2013): *Erneuerbare Energien 2012 - Daten des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit zur Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2012 auf der Grundlage der Angaben der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) – Vorläufige Angaben Stand 28. Februar 2013*. BMU, Berlin, Germany, 2013.

BürgerEnergiegenossenschaft Rotach-Schussen-Argen eG (2013): *Webseite der BürgerEnergiegenossenschaft Rotach-Schussen-Argen eG*. URL: http://www.buergerenergie-rotach-schussen-argen.de/Home.153.0.html (last time accessed 08.10.2015).

Bürgerwindpark Niebüll GmbH & Co. KG (2013): *Webseite des Bürgerwindparks Niebüll*. URL: http://www.bw-niebuell.de/ (last time accessed 08.10.2015)

Centner, T.J. (1988): The role of cooperatives in agriculture: historic remnant or viable membership organization?. In: *Journal of Agricultural Cooperation*, 3, 94-106.

Cook, M.L. (1995): The future of US agricultural cooperatives: A neo-institutional approach. In: *American Journal of Agricultural Economics*, 77 (5), 1153-1159.

Degenhart, H./ Schomerus, T. (2008): *Geschäftsmöglichkeiten mit der Finanzierung erneuerbarer Energien in Deutschland*. Leuphana University Lüneburg Working Paper Series in Business and Law Nr. 4, Leuphana Universität, Lüneburg, Germany, 2008. Working paper also available on the internet at the following address, URL: http://www.leuphana.de/fileadmin/user_upload/Forschungseinrichtungen/ifwr/files/Arbeitpapiere/WPBL-No4.pdf (last time accessed 08.10.2015).

Derrick, A. (1998): Financing mechanisms for renewable energy. In: *Renewable Energy*, 15 (1), 211-214.

Deutscher Genossenschafts- und Raiffeisenverband e.V (DGRV) (2013): *Energiegenossenschaften – Ergebnisse der Umfrage des DGRV und seiner Mitgliedsverbände – Frühjahr 2013*. DGRV, Berlin, Germany, 2013.

EnergieAgentur.NRW (2011): *Klimaschutz mit Bürgerenergieanlagen*. EnergieAgentur.NRW, Wuppertal, Germany, 2011.

Energiegemeinschaft Weissacher Tal e.G (2013): *Webseite der Energiegemeinschaft Weissacher Tal eG*. URL: http://www.energie-wt.de/ (last time accessed 08.10.2015).

Energiegenossenschaft Starkenburg eG (2013): *Webseite der Energiegenossenschaft Starkenburg eG*. URL: http://www.energiestark.de/index.html (last time accessed 08.10.2015)

Enzensberger, N., Fichtner, W./ Rentz, O. (2003a): Evolution of local citizen participation schemes in the German wind market. In: *International Journal of Global Energy Issues*, 20 (2), 191-207.

Enzensberger, N./ Fichtner, W./ Rentz, O. (2003b): Financing renewable energy projects via closed-end funds—a German case study. In: *Renewable Energy*, 28 (13), 2023-2036.

European Union (EU) (2009): *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*. Legislative text also available on the internet at the following address, URL: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV:en0009 (last time accessed 08.10.2015).

Finon, D. (2006): Incentives to invest in liberalised electricity industries in the North and South. Differences in the need for suitable institutional arrangements. In: *Energy Policy*, 34 (5), 601-618.

GLS Gemeinschaftsbank eG (2013): *GLS Sparbrief: sicher und wirksam*. URL: https://www.gls.de/privatkunden/angebote/sparen-anlegen/sparbrief-privat/uebersicht/ (last time accessed 08.10.2015).

Grau, T./ Huo, M./ Neuhoff, K. (2012): Survey of photovoltaic industry and policy in Germany and China. In: *Energy Policy*, 51, 20-37.

Harborne, P./ Hendry, C. (2009): Pathways to commercial wind power in the US, Europe and Japan: The role of demonstration projects and field trials in the innovation process. In: *Energy Policy*, 37 (9), 3580-3595.

Herlinghaus, A./ Kürten, S.-O./ Niegsch, C./ Stappel, M. (2008): *Erneuerbare Energien und Perspektiven für den Genossenschaftssektor. Konjunktur und Kapitalmarkt - Eine Research-Publikation der DZ Bank AG*. DZ Bank AG – Deutsche Zentral-Genossenschaftsbank, Frankfurt, Germany, 2008.

Holstenkamp, L. (2012): *Ansätze einer Systematisierung von Energiegenossenschaften*. Leuphana University Lüneburg Working Paper Series in Business and Law Nr. 11, Leuphana Universität, Lüneburg, Germany, 2012. Working paper also available on the internet at the following address, URL: http://www.leuphana.de/fileadmin/user_upload/Forschungseinrichtungen/professuren/finanzierung-finanzwirtschaft/files/Arbeitspapiere/typ-energiegeno_120629.pdf (last time accessed 08.10.2015).

Holstenkamp, L./ Degenhart, H. (2013): *Bürgerbeteiligungsmodelle für erneuerbare Energien – Eine Begriffsbestimmung aus finanzwirtschaftlicher Perspektive*. Leuphana University Lüneburg Working Paper Series in Business and Law Nr. 13, Leuphana Universität, Lüneburg, Germany, 2013. Working paper also available on the internet at the following address, URL:

http://www.leuphana.de/fileadmin/user_upload/PERSONALPAGES/_ijkl/janner_steve/Homepage_Master/wpbl_13.pdf (last time accessed 08.10.2015).

Holstenkamp, L./ Müller, J.R. (2013): *Zum Stand von Energiegenossenschaften in Deutschland*. Leuphana University Lüneburg Working Paper Series in Business and Law Nr. 14, Leuphana Universität, Lüneburg, Germany, 2013. Working paper also available on the internet at the following address, URL: http://www.leuphana.de/fileadmin/user_upload/PERSONALPAGES/_ijkl/janner_steve/Homepage_Master/wpbl_14.pdf (last time accessed 08.10.2015).

Jäger-Waldau, A./ Szabó, M./ Scarlat, N./ Monforti-Ferrario, F. (2011): Renewable electricity in Europe. In: *Renewable and Sustainable Energy Reviews*, 15 (8), 3703-3716.

Kemfert, C./ Schäfer, D. (2012): Financing the Energy Transition in Times of Financial Market Instability. In: *DIW Economic Bulletin*, 2 (9), 3-13.

Maron, B./ Maron, H. (2012): *Genossenschaftliche Unterstützungsstrukturen für eine sozialräumlich orientierte Energiewirtschaft*. Klaus Novy Institut e.V., Köln, Germany, 2012.

Masini, A./ Menichetti, E. (2012). The impact of behavioral factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. In: *Energy Policy*, 40, 28-38.

Mills, S.J./ Taylor, M. (1994): Project finance for renewable energy. In: *Renewable Energy*, 5 (1), 700-708.

Moore, B./ Wüstenhagen, R. (2004): Innovative and sustainable energy technologies: the role of venture capital. In: *Business Strategy and the Environment*, 13 (4), 235-245.

Oliver, M./ Jackson, T. (1999): The market for solar photovoltaics. In: *Energy Policy*, 27 (7), 371-385.

Painuly, J.P. (2001). Barriers to renewable energy penetration; a framework for analysis. In: *Renewable Energy*, 24 (1), 73-89.

PROKON Unternehmensgruppe (2013): *PROKON Genussrechte – Die Geldanlage im Bereich Erneuerbarer Energien*. URL: http://www.prokon.net/prokon-genussrechte [Note: This link isn't available anymore.]

Rau, I./ Zoellner, J. (2011): *Projektabschlussbericht – Aktivität und Teilhabe - Akzeptanz Erneuerbarer Energien durch Beteiligung steigern*. BMU/ Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany, 2011.

Sadorsky, P. (2012): Modeling renewable energy company risk. In: *Energy Policy*, 40, 39-48.

trend:research Institut/ Leuphana Universität Lüneburg (2013): *Definition und Marktanalyse von Bürgerenergie in Deutschland*. trend:research Institut/ Leuphana Universität, Bremen/ Lüneburg, Germany, 2013. Study also available on the internet at the following address, URL: http://www.buendnis-buergerenergie.de/fileadmin/user_upload/downloads/Studien/Studie_Definition_und_Marktanalyse_von_Buergerenergie_in_Deutschland_BBEn.pdf (last time accessed 08.10.2015).

Toke, D./ Breukers, S./ Wolsink, M. (2008): Wind power deployment outcomes: How can we account for the differences?. In: *Renewable and Sustainable Energy Reviews*, 12 (4), 1129-1147.

Unruh, G.C. (2000): Understanding carbon lock-in. In: *Energy Policy*, 28 (12), 817-830.

Verband Geschlossene Fonds (VGF) (2013): *VGF Branchenzahlen 2012*. Verband Geschlossene Fonds e.V. (VGF), Berlin, Germany, 2013.

Volz, R. (2010): *Stand und Entwicklungsmöglichkeiten von Bürgerenergiegenossenschaften in Deutschland*. In: Doluschitz, R. [ed.]: Aktuelle theoretische und empirirsche Beiträge zur Genossenschafts- und Kooperationsforschung. 1st ed., Forschungsstelle für Genossenschaftswesen der Universität Hohenheim, Stuttgart, Germany, 2010, pp. 37-66.

Wieg, A./ Vesshoff, J./ Boenigk, N./ Dannemann, B./ Thiem, C. (2011): *Energiegenossenschaften – Bürger, Kommunen und lokale Wirtschaft in guter Gesellschaft*. Agentur für Erneuerbare Energien (AEE) e.V./ Deutscher Genossenschafts- und Raiffeisenverband e.V. (DGRV), Berlin, Germany, 2011.

Windpark Hollich GmbH & Co.KG (2013): Webseite des Windparks Hollich GmbH & Co. KG. URL: http://www.windpark-hollich.de/ (last time accessed 08.10.2015).

Wüstenhagen, R./ Menichetti, E. (2012): Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. In: *Energy Policy*, 40, 1-10.

Wüstenhagen, R./ Teppo, T. (2006): Do venture capitalists really invest in good industries? Risk-return perceptions and path dependence in the emerging European energy VC market. In: *International Journal of Technology Management*, 34 (1-2), 63-87.

Appendix to chapter 2: Supplemental material for “Chapter 2: Financing renewable energy infrastructures via financial citizen participation – the case of Germany”

In the following, additional information and explanation on the respective ownership groups is given:

Chapter 2 – Appendix a) Citizen energy/ citizen ownership

This group covers citizen participation as described in section two. According to this, citizen participation in a narrower sense includes business models where citizens contribute at least 50% of the equity of the company and the investors stem from the region where the plant is located. This includes, for example, energy cooperatives, joint investments (by a small group of local investors), local investments (joint investments of citizens and municipalities) or closed-end funds.

Furthermore, this group also covers individual owners of facilities. Among individual owners are private and agricultural sole proprietorships, partnerships and smaller corporations (e.g. agricultural cooperatives).

Chapter 2 – Appendix b) Energy suppliers

This group includes the so called "big four" (EnBW AG, E.ON AG, RWE AG, Vattenfall Europe AG), regional energy suppliers, international energy suppliers, a residual group of other energy suppliers that do not belong to the previous categories as well as contracting and energy service companies.

Regional energy suppliers are power generation companies with an installed capacity of > 400 MW in Germany, operating in geographically defined areas, e.g. Federal states or urban agglomerations and having their corporate headquarters in Germany. Examples are EWE AG, MVV Energie AG, . RheinEnergie AG, and Stadtwerke Duisburg AG

International Energy supply companies are energy companies with corporate headquarters outside of Germany. Examples are Dong Energy A/S, GdF Suez, and Iberdrola SA**.**

This group other energy companies is similar to the group of regional energy suppliers but covers only power generation companies with an installed capacity of < 400 MW in Germany. They also operate in geographically defined areas and also have their corporate headquarters in Germany. Examples are Stadtwerke Tübingen GmbH and HEAG Holding AG/HSE.

Contracting and energy services companies are companies with a service focus in the market segment of contracting and energy services. Examples are Dalkia Energie Service GmbH, Getec Energie AG, and Cofely Deutschland GmbH.

Chapter 2 – Appendix c) Institutional and strategic investors

In the group of institutional and strategic investors, institutional investors, industry, large agricultural companies and project developers are summarized.

In detail, this group includes larger producing and manufacturing companies from industry and trade where an exemplary industrial sector being particularly active within renewable energy is the wood-processing industry which is involved in biomass based heat and power plants as well as banks, insurance companies, investment companies, and project developers whose primary or secondary business purpose is the development and sale of projects in the renewable energy sector. As these project developers are also involved in plant operation, some of the projected plants are operated by themselves and remain in their ownership. Examples are agri.capital GmbH and Aufwind Neue Energien GmbH.

Chapter 3: Energy cooperatives in Germany – growth of energy co-operatives and an analysis from an new institutional economics perspective

by Özgür Yildiz

Technische Universität Berlin

Department of Economic Policy and Environmental Economics

Journal article[10] published as:

Yildiz, Ö. (2013): Energiegenossenschaften in Deutschland – Bestandsentwicklung und institutionenökonomische Analyse. In: *Zeitschrift für das gesamte Genossenschaftswesen*, *63*(3), 173-186. http://dx.doi.org/10.1515/zfgg-2013-0303.

Abstract

The number of energy cooperatives has grown tremendously during the recent years but this growth process is characterized by several sector specific factors. Photovoltaic cooperatives account for approximately fifty percent of growth dynamics, whereas the number of bioenergy cooperatives is still relatively small. This may be due to a rather complex value creation chain as well as to considerable heterogeneity of stakeholders. The paper presented here discusses these issues from an institutional economics viewpoint.

Keywords

Renewable energy; energy cooperative; new institutional economics; transaction cost economics

Acknowledgements

The author would like to thank Matthias Latus from the journal's editorial board and two anonymous reviewers for their valuable comments on the manuscript. Furthermore, the author would also like to thank Jennifer Rogers, text editor at Cambridge

[10] This chapter was translated from the original version of the article entitled "Energiegenossenschaften in Deutschland – Bestandsentwicklung und institutionenökonomische Analyse". The style of the original paper was adapted in order to fit the formal style guidelines of this thesis. References within the text to other sections were also adapted in order to correspond with the denotation of this thesis.

Proofreading LLC (http://proofreading.org/) for language-editing of the translated version of the original article.

List of abbreviations in chapter 3

EEG	Erneuerbare-Energien-Gesetz/ Renewable Energies Act
GenG	Genossenschaftsgesetz/ Cooperative Societies Act
GenR	Genossenschaftsrecht/ Law on Cooperative Societies

3.1. Introduction

As part of the transition of the energy sector toward a broader use of renewable energy sources, German government follows different development paths and strategies to achieve the economic and environmental objectives for the year 2050, e.g. the reduction of CO_2 emissions by at least 80% compared to 1990 levels or increasing the share of renewables in gross electricity consumption by at least 80% (BGBI 2012). [11] In this context, decentralized, small-scale infrastructures play an important role since they can be flexibly designed to address local needs, they make local resource potential specifically usable and thus (at least partially) decouple the energy of global developments. Furthermore, decentralized generation could serve as a substitute for investments in transmission and distribution capacity, which could result in cost savings due to spatial proximity of production site and consumers (Pepermans et al. 2005).

However, the implementation of decentralized supply concepts faces a variety of challenges. Two major obstacles in this regard are funding problems due to suboptimal investment incentives and an insufficient organizational framework to provide a hedge for specific investments. The dynamic development of the number of energy cooperatives could lead to the assumption that cooperative forms of organization provide a remedy in this context, but the question arises as to whether the registered cooperative as an organizational form is suitable for the coordination of the complex value chain of supply structures. The following article deals with this question and carries out an analysis of energy cooperatives from the perspective of new institutional economics, in particular the transaction costs approach, to assess the effectiveness of the cooperative in terms of setting of investment incentives and the protection of specific investments by the organizational framework. Before the analytical examination of the energy cooperatives is carried out, a description of the characteristics of renewable energy cooperatives is presented in the following section.

[11] In the original paper, a reference was made to the website of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (URL: http://www.bmu.de/themen/klima-energie/energiewende/beschluesse-und-massnahmen/). As this website wasn't available anymore by the 11.10.2015, the reference was changed to the underlying legal text (BGBI 2012).

3.2. Toward a definition of energy cooperatives

Energy cooperatives in Germany exist in various forms which are also reflected in a variety of definition approaches. Common to all definitions is the characterization of the energy cooperative's business activities along the value chain in the energy sector (e.g. energy production, energy distribution). It should be emphasized that the reference to the energy sector must be the main business purpose of cooperative. Thus, energy cooperatives which among many other business activities provide as secondary business their members with fuel can't be subsumed under the concept of energy cooperative in a narrower sense (Holstenkamp 2012).

According to the above mentioned focus on business activities along the value chain, a first approach distinguishes energy cooperatives in energy service cooperatives, energy production cooperatives, and energy consumer cooperatives. Energy service cooperatives help their members through various activities such as energy consulting, contract procurement, and distribution partnerships. Hence, they bundle usually the activities of several utilities, which in turn are often organized as cooperatives. Energy consumer cooperatives mainly focus on trading and distribution of energy to the final consumer. In practice, consumer cooperatives are active in spatially limited fields as well as in nationwide active types of consumer societies. Founding motives for consumer cooperatives are usually differences with established providers regarding to certain features such as the energy price or energy source. Finally, energy production cooperatives focus on the generation and the sale of energy that they produce. Compared to the other forms mentioned, energy production cooperatives are the most widespread group (Flieger 2011).

A quite similar but broader classification identifies eleven separate activity fields along the value chain in the energy sector. Examples of the identified categories are artisan cooperatives providing services such as the organization of energy-saving measures and advisory services, innovation cooperatives for the research and development of technology, energy purchasing cooperatives, upstream product cooperatives, and energy production cooperatives (Theurl 2008).

Finally, an alternative classification that is different from the previous two approaches focuses not on the field of activity but on the underlying source of energy as a key distinctive feature. Accordingly, energy cooperatives are distinguished in photovoltaic cooperatives, cooperative community wind farms, cooperative biogas plants as well as production, service and marketing cooperatives for the use of wood or wood chips. In addition, this resource-specific classification includes cross-sectoral cooperative business models in the energy sector such as purchasing and marketing cooperatives for technical components for renewable energy generation (Herlinghaus et al. 2008).

The variety of definitions illustrates that energy cooperatives are a heterogeneous population. Hence an assignment to the various cooperative associations and various cooperative types according to the typology in § 1 para. 1 no. 1-7 (old edition) of the Cooperative Societies Act (GenG) is extremely difficult and changeable. For example, water and electricity cooperatives were until 2008 first counted among the rural cooperatives in the annual reports of the German Cooperative Publishing House regarding the development of cooperatives in Germany. Then, records from 2009 listed water and electricity cooperatives as a separate sub-category under the main category of commercial cooperatives. As a second example, bioenergy cooperatives, which were assigned to the category of commercial cooperatives until 2008, had been rearranged to the category of rural cooperatives in 2009. Thus, it is recommended for empirical studies to analyze start-up and inventory statistics of cooperative associations to display the actual activity of the cooperative model in the German energy sector (Holstenkamp 2012). The following section will present empirical data on the number of energy cooperatives in Germany, respecting the just mentioned critical points and deriving the number from the analysis of start-up and inventory statistics of cooperative associations.

3.3. The growth of energy cooperatives – historical development and status quo

Cooperative organizational structures in the energy sector have a long tradition. At the end of the 19th century, the first so-called electricity cooperatives were founded in order to implement rural structures for energy production and distribution, with a focus on network operation. Due to the strong rise in demand for electricity in the wake of economic recovery after the Second World War, the number of local electricity cooperatives fell sharply, as the existing technical facilities no longer met the requirements and were consequently displaced by larger, inter-regional power companies (Volz 2010).

Recent developments both on political-legal and social level have led in recent years to a revival of cooperatives in the energy sector. As figure 3.1. (**Fig. 3.1.**) shows, the number of energy cooperatives in Germany increased strongly starting from 66 in 2001 and to 586 energy cooperatives in 2011, with a particular dynamic growth in the period from 2007 to 2011, when over 500 energy cooperatives were initiated (Maron and Maron 2012).

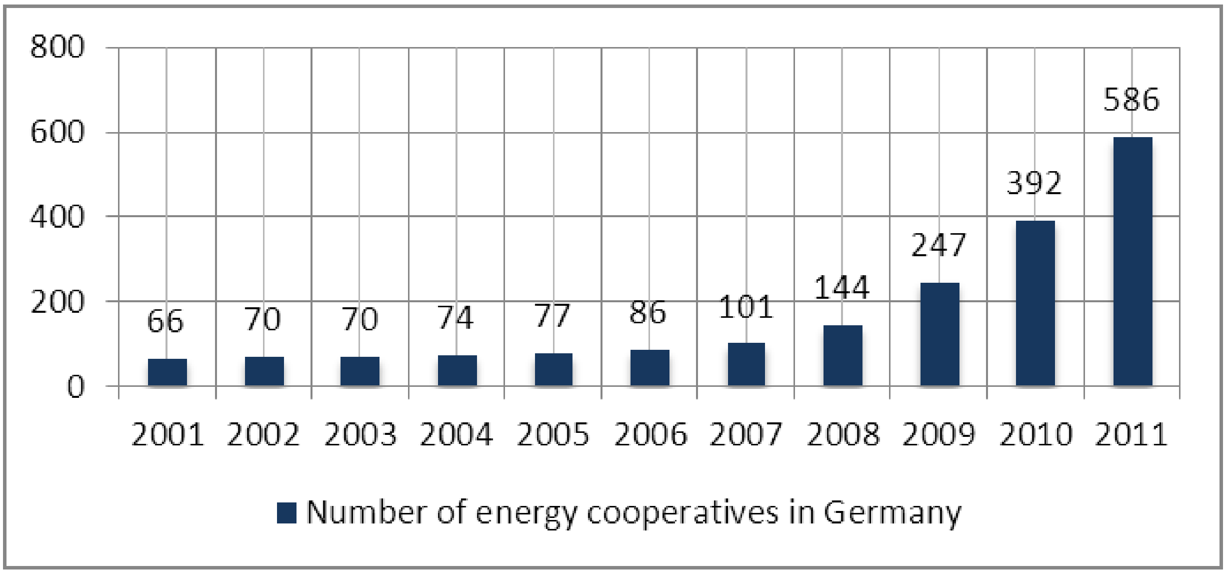

Fig. 3.1.: Number of energy cooperatives in Germany.
(Source: Author's design, based on Maron and Maron 2012).

The comparison of the number of energy cooperatives to the overall development in the cooperative sector shows that energy cooperatives are taking an increasingly strong position among cooperatives in general. Accordingly, the relative share of energy cooperatives among the total number of cooperatives in Germany increased from 4.81% in 2010 to 6.94% in the following year. Here, high concentrations of about 9 -10% from the total number of cooperatives (just under 15% in Lower Saxony) can be found especially in Lower Saxony, Bavaria, Baden-Württemberg, and Hesse. A more in-depth analysis of the density values per 100,000 population also reveals that this strong regional concentration is not only due to the large population of certain regions, because even with this parameter, the first three of these provinces have the highest values (Baden-Württemberg 0.99 Energy cooperatives per 100,000 inhabitants; Bavaria and Lower Saxony about 1.20 energy cooperatives per 100,000 inhabitants) (Maron and Maron 2012).

Finally, a division-specific analysis reveals special distribution characteristics that are of particular interest for the institutional economic analysis of energy cooperatives to follow. Here, photovoltaic cooperatives play an important role, particularly in smaller communities (up to 50,000 inhabitants) as 50% of energy cooperatives registered in this municipality size class rely on the use of solar energy. The photovoltaic cooperatives are followed at a distance by the collective category of "bioenergy, wind and hydro power" and energy cooperatives focusing on grid operation (Maron and Maron 2012).

3.4. An analysis of energy cooperatives from a new institutional economics perspective

The described dynamic development in the field of energy cooperatives, particularly in rural areas, raises the question of what this rapid growth was due. A first explanation can be found in the amendment to the law on cooperative societies (GenR) which facilitated the realization of cooperative entities and therefore led to a general revival of the cooperative as an organizational form and business model. Other motives can be found in the legal promotion of renewable energy through the Renewable Energy Sources Act (EEG), which also underwent a revision in 2009 and led to an expansion of the use of renewable energy sources in general (Doluschitz et al. 2012).

In addition to these external factors, it is also of interest to look at internal organizational aspects in order to analyze the growth of energy cooperatives of interest, in particular the coordination of the various value chain and associated costs. Therefore, an analysis of energy cooperatives based on the transaction cost approach is conducted in the further course starting with a general introduction to the theoretical foundations of the transaction cost approach.

3.4.1. The foundations of new institutional economics and the transaction cost approach

The new institutional economics provides a multifaceted analytical instrument to study the relationships and interactions between framework-setting constructs such as organizational forms, contracts, legal rules, or social norms (subsumed under the term "institution") and their effects on the actions of economic actors in an economic exchange. It is divided into several sub-disciplines, e.g. the so-called property rights theory (also known as incomplete contract theory), which focuses on the assignment of property rights and its effects on the behavior of economic agents given incomplete contractual arrangements in the presence of asymmetric information among involved agents, the transaction cost approach that examines the cost efficiency of organizational systems and operational coordination mechanisms based on the comparison of transaction cost structures, and the principal-agent theory that deals with incentive structures and control mechanisms to deal with frictions resulting from information asymmetries between an economic agent who authorizes (principal) and another economic agent to act on behalf of his name (agent) (Picot 2005).[12]

In the further course, the transaction cost approach is explained in more detail as it is the central analytical framework for the institutional economic analysis of energy cooperatives.

The initial thoughts on the size of a firm and the design and organizational setting of an economic exchange date back to the work of Ronald Coase (1937). Starting from the analysis of costs for the use of the price mechanism of the market, Coase developed an analytical approach for comparing different coordination mechanisms for the exchange of services and other economic transactions by economic agents. Accordingly, the costs of using market mechanisms for an economic exchange stem primarily from efforts to acquire information on prices and (potential) trading partners, from efforts to negotiate and to conclude contracts, and to monitor agreements. Additional costs can result from modifying and enforcing contracts, so that the co-ordination of a determined economic exchange within a hierarchically organized company can be more efficient with regard to the costs incurred (Coase 1937).

Building on Coase's work, his analytical approach for determining the size of a company and regarding the analysis of operational coordination mechanisms has been continually developed. Hence, so-called transaction costs to analyze the efficiency of alternative forms of coordination were introduced, and relevant behavioral assumptions as well as actual transaction characteristics were determined in detail. According to this, any exchange of a good or service via a technically separable interface is defined as a transaction. This exchange is subject to costs that are the "*economic equivalent of friction in physical systems*" (Williamson 1985:19), the transaction costs. These costs incur due to the use of institutions of the economic system and related efforts as mentioned above by Coase (Williamson 1985).

Underlying to transaction costs are specific behavioral assumptions. According to this, the so-called bounded rationality of economic agents and opportunistic behavior are particularly relevant. Here, bounded rationality implies that individuals aspire to

---

[12] Besides the above mentioned sub-disciplines, the literature on new institutional economics sometimes also comprises further research fields such as so called public choice theory and constitutional economics.

act rationally (in the sense of an omniscient agent) but are restricted in doing so by cognitive limitations. Opportunistic behavior follows from the aim of individual utility maximization and can even include behavioral patterns such as deceitfulness and fraud in order to maximize individual utility (Williamson 1985). Furthermore, the properties of a transaction are decisive as they determine its transaction costs. These properties are the transaction specificity and the closely related strategic relevance of the transaction, the transaction frequency, the uncertainty ongoing with the transaction (divided into the dimensions of behavioral and environmental uncertainty) as well as the social, cultural, and technological environment of each transaction (Eekhoff 2005).

Within this context, a central role is played by specificity. It is divided into different dimensions, such as site, asset, and human capital specificity and describes the possibility of an alternative use of assets and resources involved in a transaction. The specificity is the higher; the more the dedicated use of a resource or an asset differs from its second-best purpose of use. A high degree of specificity can lead to the so-called lock-in effect: an exchange-based dependency which can be exploited opportunistically by one of the exchange parties through the appropriation of relationship-specific rents. Consequently, concerns regarding the possible appropriation of returns usually play a crucial role in the assessment of the transaction cost efficiency of a given governance structure for an economic exchange (Williamson 1985).

Thus, it follows from the analysis of the transaction costs approach that vertical integration of a value-added chain with specific investment may be advisable in order to avoid high transaction costs as a result of opportunistic behavior. Here, the authority and related rights to give directives within a vertically integrated firm avoid possible deviations from contractual agreements and resulting transaction costs (Williamson 1971).

3.4.2. Energy cooperatives from a new institutional economics perspective

Considering their main characteristics, cooperatives in general, and consequently also energy cooperatives, can be classified as hybrids within the new institutional economics' typology of governance structures ranging from market to hierarchical organization. Members pool some, but not all, of their qualifications and resources in the cooperative enterprise's business. Hence, members still remain economically independent, and consequently can use their qualifications and resources also for other tasks. Consequently, the cooperative has features that provide benefits in terms of integrating transactions into a collective organization while allowing independence of other operational aspects so that it is in some cases superior to the market and the hierarchical organization regarding its transaction cost efficiency (Higl 2008).

In more detail, the advantage of the cooperative organization in the energy sector in terms of transaction costs and other factors can be explained by different characteristics. From a production cost perspective, energy cooperatives have compared to the market relationship the advantage that the members can profit from potentials for greater economies of scale in energy production and energy purchase than from a trade with external partners (e.g., utilities, electricity market) (Higl 2008).

From a transaction cost perspective, energy cooperatives are preferable to market transactions when an underlying exchange is characterized by a higher specificity than the exchange of a standardized product or service. Given high specificity, the integration of the entire value-added process in a cooperative organization can avoid high transaction costs due to opportunistic behavior of external trade partners (Bonus 1986).

However, it has to be noted that the relationship between the transaction property "specificity" and the level of transaction costs has to be reflected on thoroughly. First, the interaction of the specificity with the other mentioned transaction properties is such, as the uncertainty or the frequency of transactions is also crucial, that these interactions need to be considered during the investigation of a transaction cost-efficient form of organization. Second, there are different perceptions in the literature as to what degree of specificity hybrid coordination mechanisms dispose an advantage over other coordination mechanisms in terms of transaction costs. Accordingly, hybrid coordination mechanisms are considered in some parts of the literature as advantageous in varying degrees of specificity from medium to high specificity, whereas other strands in the literature strictly recommend hierarchical coordination with high transaction specificity (Williamson 1991).

This relationship between the specificity of a transaction and the organizational form will be displayed in the following with the comparison of energy cooperatives using bioenergy respectively solar energy. These two examples and the underlying technologies are substantially different from each regarding the involved transactions.

Consequently, they are particularly suited to display differences in specificity and conclusions for organizational forms.

Bioenergy cooperatives are characterized by a complex value-addition process, which includes among others the extraction and provision of raw materials, the energetic exploitation of these raw materials, as well as the distribution of production output and the marketing of by-products. The exchange of services along this value-addition process includes regularly specific investments (e.g., site specificity; investments in specific technical equipment and other assets that are designed according to specific input factors). Consequently, this high specificity requires an institutional setting which helps to avoid high transaction costs possibly resulting from opportunistic behavior (Altman et al. 2007).

Starting from these concerns on opportunistic behavior and the consequential requirement for a suited institutional setting, an intuitive call for a cooperative organization of bioenergy structures could be derived. Here, the cooperative as a coordination mechanism proves to be more cost-effective than market relations regarding the underlying transaction costs, as the higher degree of integration reduces the transaction costs that might result from opportunistic behavior. However, there are some arguments that conflict with this intuition. Some actors involved in a cooperative, such as resource suppliers, are not only cooperative members, but are also in an economic relationship with the cooperative. This relationship is often characterized by specific investments (site specificity, physical capital specificity). Thus, these actors are economically still independent and face a trade-off that still allows for opportunistic behavior and, consequently, can lead to high transaction costs, as the following example shows.

A supplier of a resource (e.g., corn for a biogas plant) receives from the bioenergy cooperative (in which he himself is a member) a compensation for the provided resources. In the course of his membership to the cooperative and the parallel business relation, the resource provider must now deal with a conflict of interest, i.e. whether he prefers to maximize the profit of his farm for the cultivation of the raw material or increase the profits of the energy cooperative by reducing the resource price. In this case, it is consequential that the decision of a purely self-utility-maximizing actor is favorable to its own farm, as in the cooperative also other actors participate in the gains that result of savings in raw material costs. Thus, it may be worthwhile for the raw material supplier to deviate from supply contracts or to ask for renegotiations.

To conclude, the potential of opportunistic behavior and related risks of high transaction costs still exist in a cooperative-based bioenergy structure so that a more hierarchical coordination mechanism seems to be a more efficient organizational form from the perspective of transaction costs.

In contrast, solar energy cooperatives are less prone to these problems. Here, the economic exchange is characterized by a lower specificity compared to bioenergy infrastructures, since the underlying process is essentially the joint acquisition and operation of partially customized, technical equipment (photovoltaic installation, distribution technology). Taking into account this middle degree of transaction specificity overall, it is consequent that the cooperative as a business model has particular significance in the domain of photovoltaics as the cooperative as an organizational form in the field of photovoltaics disposes of advantages related to transaction cost efficiency (Holstenkamp and Ulbrich 2010).[13]

This advantage over a hierarchical organization arises from the fact that the internal organizational costs of hierarchical coordination, representing the transaction cost of this type of organization, are higher than the transaction costs of the cooperative organization. The cooperative has lower costs of internal organization but must deal with the risk of opportunistic behavior. Here, the particular form solidarity within a cooperative (the "cooperative spirit"), strengthens mutually the loyalty of stakeholders so that incentives for opportunistic behavior are mitigated. Hence, the overall assessment of transaction costs proves cooperatives to be more efficient as an organizational form compared to hierarchical organization for the case of photovoltaics. Concerning market transactions, the medium specificity of the value chain makes a joint coordinating institution necessary. Hence, market transactions are also comparably inefficient compared to the cooperative organization (Higl 2008).

However, to complement the preceding analysis, it should be noted that the “cooperative spirit” within the framework of energy cooperatives is affected by various factors, such as the size of the cooperative (measured by the number of members), the individual preferences of cooperative members on pro-social behavior, and the heterogeneity of interests among the various cooperative members. Here, a high num-

[13] Besides the above-mentioned explanation from an internal perspective, external factors such as the reform of the Cooperatives Act, the launch of various start-up activities on the part of the cooperative unions, and the dynamic development of the photovoltaic sector as a result of realized changes of the Renewable Energy Law (Erneuerbare-Energien-Gesetz – EEG) also played an important role in the dynamic development of cooperatives in the photovoltaic sector (Holstenkamp and Ulbrich 2010).

ber of members, a strong heterogeneity of interests, and strong preferences for self-utility-maximization impairs the “cooperative spirit” (Ribhegge 1986).

Thus, the relatively low share of bioenergy cooperatives in the total number of energy cooperatives (cf. section 3.3.) can be explained among other things by the high specificity of the underlying value creation process and the strong heterogeneity of interests so that a hierarchical organization turns out to be the more efficient alternative for bioenergy infrastructures in terms of transaction costs.

3.5. Conclusions and outlook

Photovoltaic cooperatives can be identified as the driving force behind the overall dynamic development in the field of energy cooperatives (cf. section 3). The reason for this is in addition to a number of external factors the transaction costs efficiency of the photovoltaic cooperative as an organizational form. For other sectors, especially bioenergy, the transaction cost efficiency must be assessed as critical; therefore, this aspect is an indication for the relatively low numbers of bioenergy cooperatives.

The fact that cooperative structures still exist in all central fields of activity in the energy sector suggests that there must be conditions under which the cooperative organization has efficiency advantages over other coordination mechanisms even in areas that are critical from an institutional economics perspective (e.g., the bioenergy sector). Against this background, further research could address the question of minimum and maximum specificity that turn cooperative forms of coordination efficient (Higl 2008).

Further research fields that promise new insights for the analysis of energy cooperatives are also the other disciplines of new institutional economics. Accordingly, the analysis of the distribution of property rights and thereby induced investment incentives can help to better understand underinvestment behavior due to the anticipation of opportunistic behavior (Grossman and Hart 1986).

Finally, the integration of insights from behavioral economics to the institutional economic analysis presented in this paper can also be a starting point for further investigations. As mentioned above, the phenomenon of “cooperative spirit” indicates that pro-social behavioral patterns can have a decisive impact on the successful operation of a cooperative. Accordingly, it must be examined whether the consideration of social preferences leads to analytical results that explain the formation of cooperatives not only in the energy sector but also in other branches.

3.6. Literature

Altman, I.J./ Sanders, D.R./ Boessen, C.R. (2007): Applying transaction cost economics: A note on biomass supply chains. In: *Journal of Agribusiness*, 25 (1), 107-114.

Bonus, H. (1986): The cooperative association as a business enterprise: a study in the economics of transactions. In: *Journal of Institutional and Theoretical Economics (JITE)/ Zeitschrift für die gesamte Staatswissenschaft*, 142 (2), 310-339.

Bundesgesetzblatt (BGBl) (2012): Erneuerbare-Energien-Gesetz vom 25. Oktober 2008 (BGBl. I S. 2074), das zuletzt durch Artikel 5 des Gesetzes vom 20. Dezember 2012 (BGBl. I S. 2730) geändert worden ist. Legislative text also available on the internet at the following address, URL: http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&start=//*%255B@attr_id=%27bgbl108s2074.pdf%27%255D#__bgbl__%2F%2F*[%40attr_id%3D%27bgbl108s2074.pdf%27]__1444303282397 (last time accessed 11.10.2015).

Coase, R.H. (1937): The nature of the firm. In: *Economica*, 4 (16), 386-405.

Doluschitz, R./ Haug, H./ Reifschneider, A. (2012): Analyse der Neugründungen von Genossenschaften–Ergebnisse einer empirischen Untersuchung im Verbandsgebiet Baden-Württemberg. In: *Zeitschrift für das gesamte Genossenschaftswesen* (ZfgG), 62 (1), 19-34.

Eekhoff, T. (2005): *Zur Wahl der optimalen Organisationsform betrieblicher Zusammenarbeit – eine gesamtwirtschaftliche Perspektive*. Arbeitspapiere des Instituts für Genossenschaftswesen der Westfälischen Wilhelms-Universität Münster Nr. 51/2005, Instituts für Genossenschaftswesen der Westfälischen Wilhelms-Universität Münster, Münster, Germany, 2005.

Flieger, B. (2011): *Energiegenossenschaften – Eine klimaverantwortliche, bürgernahe Energiewirtschaft ist möglich*. In: Elsen, S. [ed.]: Ökosoziale Transformation – Solidarische Ökonomie und die Gestaltung des Gemeinwesens – Perspektiven und Ansätze der ökosozialen Transformation von unten. AG SPAK Bücher, Neu-Ulm, Germany, 2011, pp. 305-328.

Grossman, S.J./ Hart, O.D. (1986): The costs and benefits of ownership: A theory of vertical and lateral integration. In: *Journal of Political Economy*, 94 (4), 691-719.

Herlinghaus, A./ Kürten, S.-O./ Niegsch, C./ Stappel, M. (2008): *Erneuerbare Energien und Perspektiven für den Genossenschaftssektor. Konjunktur und Kapitalmarkt - Eine Research-Publikation der DZ Bank AG*. DZ Bank AG – Deutsche Zentral-Genossenschaftsbank, Frankfurt, Germany, 2008.

Higl, M. (2008): *Theorie der Genossenschaft – Eine industrieökonomische Analyse*. Peter Lang Verlag, Frankfurt am Main, Germany, 2008.

Holstenkamp, L. (2012): *Ansätze einer Systematisierung von Energiegenossenschaften*. Leuphana University Lüneburg Working Paper Series in Business and Law Nr. 11, Leuphana Universität, Lüneburg, Germany, 2012. Working paper also available on the internet at the following address, URL: http://www.leuphana.de/fileadmin/user_upload/Forschungseinrichtungen/professuren/finanzierung-finanzwirtschaft/files/Arbeitspapiere/typ-energiegeno_120629.pdf (last time accessed 11.10.2015).

Holstenkamp, L./ Ulbrich, S. (2010): *Bürgerbeteiligung mittels Fotovoltaikgenossenschaften – Marktüberblick und Analyse der Finanzierungsstruktur* . Leuphana University Lüneburg Working Paper Series in Business and Law Nr. 8, Leuphana Universität, Lüneburg, Germany, 2010. Working paper also available on the internet at the following address, URL: https://www.leuphana.de/fileadmin/user_upload/Forschungseinrichtungen/ifwr/files/Arbeitpapiere/WPBL8-101215.pdf (last time accessed 11.10.2015).

Maron, B./ Maron, H. (2012): *Genossenschaftliche Unterstützungsstrukturen für eine sozialräumlich orientierte Energiewirtschaft*. Klaus Novy Institut e.V., Köln, Germany, 2012.

Pepermans, G./ Driesen, J./ Haeseldonckx, D./ Belmans, R./ D'haeseleer, W. (2005): Distributed generation: definition, benefits and issues. In: *Energy policy*, 33 (6), 787-798.

Picot, A. (2005): *Der Beitrag der Institutionenökonomik zur Entwicklung der Wirtschaftswissenschaften*. In: Hasse, R./ Vollmer, U. [eds.]: Incentives and Economic Behavior - Schriften zu Ordnungsfragen der Wirtschaft Band 76. Lucius & Lucius Verlag, Stuttgart, Germany, 2005, pp. 1-13.

Ribhegge, H. (1986). Genossenschaftsgesinnung in entscheidungslogischer Perspektive. In: *Kyklos*, 39 (4), 574-595.

Theurl, T. (2008): *Klimawandel – Herausforderungen und Tätigkeitsfelder für Genossenschaften*. In: Institut für Genossenschaftswesen der Westfälischen Wilhelms-Universität Münster [ed.]: IfG Intern Newsletter 1/2008. Institut für Genossenschaftswesen der Westfälischen Wilhelms-Universität Münster, Münster, Germany, 2008, pp. 19-22.

Volz, R. (2010): *Stand und Entwicklungsmöglichkeiten von Bürgerenergiegenossenschaften in Deutschland*. In: Doluschitz, R. [ed.]: Aktuelle theoretische und empirirsche Beiträge zur Genossenschafts- und Kooperationsforschung. 1st ed., Forschungsstelle für Genossenschaftswesen der Universität Hohenheim, Stuttgart, Germany, 2010, pp. 37-66.

Williamson, O. E. (1971): The vertical integration of production: market failure considerations. In: *The American Economic Review*, 61 (2), 112-123.

Williamson, O. E. (1985): *The Economic Institutions of Capitalism*. The Free Press, New York, NY, 1985.

Williamson, O. E. (1991): Comparative economic organization: The analysis of discrete structural alternatives. In: *Administrative Science Quarterly*, 36 (2), 269-296.

Chapter 4: A microeconomic analysis of decentralized small scale biomass based CHP plants – the case of Germany

by

Dr. Nadine Wittmann

Technische Universität Berlin

Department of Economic Policy and Environmental Economics

and

Özgür Yildiz

Technische Universität Berlin

Department of Economic Policy and Environmental Economics

Journal article[14] published as:

Wittmann, N./Yildiz, Ö. (2013): A microeconomic analysis of decentralized small scale biomass based CHP plants – The case of Germany. In: *Energy policy*, *63*, 123-129. http://dx.doi.org/10.1016/j.enpol.2013.05.069.

Abstract

Alternative energy sources, such as biomass combined heat and power (CHP) plants, have recently gained significantly in importance and action is due both on the large scale corporate level and on the small scale. Hence, making the scope and economic outline of such projects easily intelligible without losing relevant details seems a key factor to further promote the necessary developments. The model setup presented in this paper may therefore serve as a starting point for generating numerical results based on real life cases or scenarios. Its focus lies on the economic analysis of decentralized biomass CHP plants. It presents a new approach to analyzing the economic aspects of biomass CHP plants implementing a formal microeconomic approach. As Germany claims a leading role in the market for renewable energy production, the paper also takes a closer look on the effects of German energy policy with respect to biomass CHP plants.

[14] The style of the original paper was adapted in order to fit the formal style guidelines of this thesis. References within the text to other sections were also adapted in order to correspond with the denotation of this thesis.

Keywords

Biomass, Renewable Energy, CES Production Function

Acknowledgements

We would like to thank Pio Baake for his valuable and constructive remarks on the subject matter, especially on the topic of nested CES production functions. Also, we would like to thank Steve McCorriston for his valuable comments on our paper. Finally, the authors would like to thank Alexander C. Pusch (successful publishing) for language-editing.

List of abbreviations in chapter 4

B-CHP	biomass combined heat and power
BGBl	Bundesgesetzblatt/ Federal Law Gazette
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit/ Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMWi	Bundesministerium für Wirtschaft und Energie/ Federal Ministry for Economic Affairs and Energy
CES	constant elasticity of substitution
CHP	combined heat and power
DBFZ	Deutsches Biomasseforschungszentrum e.V./ German biomass research centre
EEG	Erneuerbare-Energien-Gesetz/ Renewable Energy Sources Act
FIT	feed-in tariff
FNR	Fachagentur Nachwachsende Rohstoffe/ German coordinating agency for renewable resources
FOC	first order conditions
KWK	Kraft-Wärme-Kopplung/ power-heat cogeneration
RC	related costs
ROI	return on investment
SK	Stoffklasse/ input factor category
SUB	subcategory of an input factor category (SK)

List of symbols in chapter 4

A, a_1, a_2	positive parameters, reflecting technological standards and related efficiency levels
β	threshold for certain input factors
c^F	fixed costs of the CHP plant
$F(y)$	overall combined output of a CHP plant
$\bar{F}(y)$	a B-CHP's maximum capacity installed
i	input factor category/ "Stoffklasse" (SK)
j	specific kind of input factor or subcategory (SUB) of SK i.
K	total capital invested in a project
kw	kilowatt
kWh	kilowatt hour
$L(y)$	function of the amount of losses, stemming from the production process and related to the amount of biogas *y* generated
$\vec{m}_{ij}$	specific input factor used (e.g. corn, manure), with variable i defining the "Stoffklasse" (SK) – i.e. input factor category – of the respective input factor and j defining the specific kind of input factor or subcategory (SUB) of SK i.
$m^3 BG$	cubic meter of biogas
MW	mega watt
$n \in N^+$	number of nested CES functions
ϕ	electrical, thermal or total energy conversion efficiency coefficient multiplied with the factor 10
$\Phi(y)$	function of the amount of electricity produced, depending from the amount of biogas *y* generated (
$\omega(y)$	function of the amount of heat produced, depending from the amount of biogas *y* generated
$\vec{p}_{ij}$	price of a specific input factor
p^e	marginal revenue for electricity generated
p^r	marginal revenue for remainders resulting as by-product of biogas production

p^{ω}	marginal revenue for heat generated
π	desired level of return on investment
$R(y)$	function of remainders from biogas production that can also be sold
ρ	substitution parameter
σ	elasticity of substitution between input factors
tFM	tons per solid cubic meter
χ	threshold for the percentage of heat output that has to be used at the least
y_n	amount of biogas output of a specific CHP plant *n*

4.1. Introduction

All over the world, the will to bring about a change in conventional energy production has been witnessed in both the social and political spheres, as manifested in documents or international events such as the Kyoto Protocol or Rio +20. To achieve the ambitious goals concerning CO_2 reduction, several measures are taken all over the world to significantly enlarge the scope of renewable energy production, both on a large scale and centralized or small scale and decentralized level. Aside from large projects such as North Sea wind parks or extensive solar parks, biomass has been considered a crucial and promising input factor to renewable energy generation (Hall 1991). Even from early on, the potential of small-scale combined heat and power (CHP) plants has been analyzed (Evans 1993; Verbruggen et al. 1993). Due to the European Union's (EU) ambitious goals set to fight and mitigate climate change both the political and the scientific importance of the renewable energy potential of biomass and CHP plants has increased even further (Berndes and Hansson 2007).

Scientific research on biogas based CHP plants is vast and substantial. Different aspects like the comparison of CHP systems with other technical concepts such as heat-only production (Wickart and Madlener 2007), the trade-off between the use of biogas to CHP or as a transport fuel (Goulding and Power 2013), the technological choice given a certain input factor scenario (Di Corato and Moretto 2011), the assessment of the optimal sight (Rentizelas and Tatsiopoulos 2010) or optimal size (Walla and Schneeberger 2008) for a biogas based CHP plant or the analysis of the link between biogas plant performance factors on total substrate costs (Stürmer et al. 2011) have been reviewed. Despite this broad research on biogas based CHP plants, microeconomic analyses are sparse. Consequently our approach fills a significant research gap in this field. Furthermore, it is of significant practical importance as the scope and economic outline of a project are easy to grasp while still containing all the relevant details. In addition, it also creates a starting point for generating numerical results based on real life cases or scenarios.

With respect to the potential of small-scale CHP plants, however, the political and economic landscape of several EU nations has also been studied in detail. Evans (1993) as well as Toke and Fragaki (2008) have taken a look at the UK while Gokcol et al. (2009) have focused on Turkey. Nonetheless, among EU nations, Germany is known for being one of the main actors in the shift towards renewable energy systems.[15] Various significant political and economic measures were taken during the last decade, which have been further accelerated since the disastrous events which occurred in Fokushima in 2011. An extensive study and resulting publication by König (2011) dealing with the German energy system shows that biomass CHP (B-CHP) plants may serve as promising measure to achieve both emission reduction as well as energy generation targets.

While this important study deals with comparing different types of biomass usage for energy production, we chose a different starting point for our analysis. In our paper, a formal microeconomic analysis and a numerical simulation of decentralized energy production based on B-CHP is conducted. We apply a nested constant elasticity of substitution (CES) production function approach to minimize the input costs of B-CHP. This approach has, to our knowledge, not been applied to B-CHP before.

Moreover, as it is the case that B-CHP are eligible for certain types of subsidies and benefits under the German feed-in tariff (FIT) system - depending on the scale of the plant and the input factors used – the effects of and changes in this significant energy policy instrument are also incorporated into the analysis.

The paper is structured as follows: Section two provides a short overview of the general framework by describing recent developments in the German energy sector and touching upon the technical characteristics of a CHP plant and the distribution of CHP plants in Germany. Then, a brief summary of the theoretical background and related work in the field as well as the formal model setup is presented and analyzed. Section four illustrates the applicability of the model by a numerical example. Finally, section five is comprised of concluding remarks.

4.2. General Framework

4.2.1 Status-Quo of Renewable Energy in Germany

The contemporary political and legal environment of the German energy sector is primarily determined by the strategic decision of the German government towards an intensified usage of renewable energies in 2010 (BMWi and BMU 2010). In 2011, this strategic focus was complemented by the decision for a nuclear power phase-out by the end of the year 2022 (BGBl 2011a). Also, various other ambitious goals were set, such as the reduction of greenhouse gas emissions by over 80% (compared to 1990)

[15] See http://www.bmu.de/en/topics/climate-energy/renewable-energy/general-information/ for further detail. [Note: this webpage is not available anymore].

by 2050, or a decrease of primary energy consumption by over 50% in 2050 (compared to 2008). Eventually, the share of renewable energy is supposed to amount to at least 80% of gross final electricity consumption in 2050.

Following these decisions, Germany's already remarkable efforts on developing renewable energy technologies and realizing renewable energy infrastructures increased significantly. In 2011, the share of renewable sources with respect to total end-users' energy consumption (electricity, heat, fuels) amounted to 12.5% out of which approximately 67% came from bioenergy. Regarding electricity production, 20.3% (17.1 in 2010) of gross end-users' electricity consumption was provided by renewable energy sources out of which approximately 10% were generated by solid or liquid biogenic combustibles and 14% by biogas. Concerning heat production, renewable energy accounted for about 11% of gross end-users' heat production in 2011. Regarding the latter, biogenic resources play a particularly significant role, since approximately 91% of aggregate renewable heat production stems from biogenic resources (BMU 2012).

Even though these empirical findings show quite a significant expansion of renewable energy systems over the past years, there are several obstacles in the way of achieving the respective targets. Among those, the expansion of the electricity grid currently has the highest priority on the political agenda, while the financing of the energy transition in general proves to be the main challenge. According to the results of several different studies, cumulative investment of approximately 235-335 billion Euros (for detailed information see Erdmann 2011; Bräuninger and Schulze 2012) will be required for a successful transition. However, attaining funding from outside investors is proving to be difficult as investments in renewable energy are still classified as innovative and therefore as high risk. Consequently, a large part of the investments comes from private individuals who are mainly involved in local, decentralized projects. Overall, private financiers account for 40% of installed capacity in the entire renewable energy sector. Additional capital for local projects is also provided by farmers, who account for around 11% of aggregate investments in renewable energy systems (Kemfert and Schäfer 2012).

4.2.2 Biogas based CHP systems in Germany

CHP systems play an important role in climate change mitigation as they provide the prospect of efficient utilization of primary energy resources and a reduction of CO_2

emissions. The key characteristic of a CHP system is its inherent capability to simultaneously produce heat and electric power. Compared to single output systems (e.g. the separate generation of heat in boilers or the generation of power in condensing plants), co-generation achieves higher energy efficiency levels of up to 90%. Consequently, fuel savings between 10 to 40% (depending on the technology used and the system replaced) can be attained. In principle various technological approaches are possible. The most widespread technical approaches involve steam turbines, steam piston engines, combined-cycle power plants and gas turbines (Madlener and Schmid 2003).

It has proven quite difficult to assess the number of biogas based CHP systems installed. Studies focusing on CHP systems in Germany analyse either CHP in general and therefore provide cumulative data on biogas and natural gas CHP systems or they offer studies on biogas based energy infrastructures in general without differentiating between electricity- or heat-only systems or co-generation units. This paper focuses primarily on data from the German biomass research centre (Deutsches Biomasseforschungszentrum (DBFZ)) which, according to its own statements, covers 90% of all registered biogas plants in Germany. Therefore, it provides a solid data base for assessing the aggregate number of biogas CHP systems installed in Germany. According to the DBFZ, 7055 biogas based plants were in operation in Germany in 2011, of which the majority (about 85%) has a maximum installed electric capacity of equal to or less than 500 MW. In general, these plants are spread out evenly across the country aside from clustering in Bavaria, Lower Saxony and sparsely populated areas in the Rhine-Main-Mosel area. In order to determine the number of CHP systems among the total number of German biogas plants installed, it is helpful to investigate how many plants received the so called Kraft-Wärme-Kopplung (KWK)-Bonus payment. According to the German FIT-system, this additional incentive was paid until 2012 for any co-generation plant. Hence, identifying the number of plants that received the KWK-Bonus payment is a valid indication of the number of biogas based CHP systems. Corresponding to the DBFZ database, almost 80% of the registered 7055 biogas plants received the KWK-Bonus payment. Consequently, the total number of biogas based CHP plants in Germany was around 5500 in 2011. For Biogas plants that were constructed in 2012 or later, co-generation of heat and electricity is mandatory (Witt et al. 2012).

4.3. The Model

4.3.1. Theoretical Background

Our microeconomic analysis of B-CHP production is based on a model setup using a nested CES production function approach, such as shown in Prywes (1986) or Kemfert (1998). Fundamental to this setup are seminal papers by Arrow et al. (1961), Uzawa (1962) and McFadden (1963). A detailed and concise overview of the history of nested CES functions can be found in Papageorgiou and Saam (2008). Especially the work of Sato (1967) has been of great importance. In case of B-CHP plants a given constant elasticity ratio between different input factors exists. Hence, a nested CES function approach proves appropriate to model the underlying B-CHP production process.

The model setup is conducted in several steps. The optimization program is deducted given relevant constraints, production technology and specific input/ output specifications. In the following setup, a representative B-CHP plant owner intends to minimize production costs in terms of substrate costs, as these variable costs turn out to be the most significant and also the most volatile cost factor provided a given installed maximum capacity (Kaphengst and Umpfenbach 2008).

4.3.2. B-CHP Production Function

The adaptation of the theoretical background in section 4.3.1. for our purpose leads to the following formal framework: There are $n \in N^+$ nested CES functions. The number of CES production function subsets needed depends on the number of different inputs factors used. The following graph (**Fig. 4.1.**) illustrates the setup:

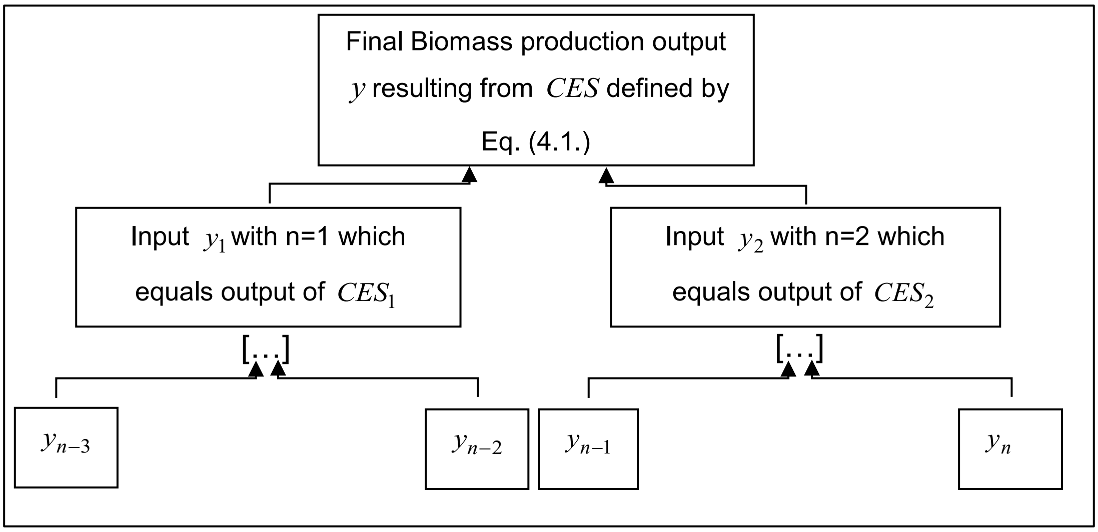

Fig. 4.1.: Scheme of a nested CES production function.
(Source: Authors' design, based on Arrow et al. (1961); Uzawa (1962), and McFadden (1963)).

Hence, final B-CHP biogas output *y*, measured in $m^3 BG$ (cubic meter of biogas) is therefore determined by the CES function without subscripts

$$CES: y = A\left[a_1 y_1^{-\rho} + a_2 y_2^{-\rho}\right]^{-1/\rho}. \tag{4.1.}$$

Where a_1, a_2 and *A* are positive parameters which reflect technological standards and efficiency levels. ρ is the so-called substitution parameter which is directly correlated to the value of σ which denotes the elasticity of substitution between input factors (see also Chiang 1984).

The technological and chemical processes of a B-CHP plant are highly complex and will not be discussed in detail.[16] In most cases, the plant is constructed to operate using only a confined selection of input factor categories which are used in a predetermined ratio range. The number of the latter usually ranges somewhere between two to four categories (Eder and Kirchweger 2011). Hence, in the following, we assume that $n = \{1, 2\}$ without the loss of generality.

B-CHP production can now be illustrated as follows: There are a minimum of two and a maximum of four input factors which are used within the $n = \{1, 2\}$ model setup. The unit of measurement of input factors is denoted by $[tFM]$ which, in the course of the B-CHP production process renders $m^3 BG.$ Regarding the German FIT, there are two

[16] For more information see Dong et al. 2009.

different kinds of input factor categories, i= I,II available, out of which j input factors are chosen. In the following, a combination of two to four input factors is assumed to be combined in a representative B-CHP plant (**Fig. 4.2.**).

$$CES: y = A\left[a_1 y_1^{-\rho} + a_2 y_2^{-\rho}\right]^{-1/\rho}$$

$$CES_1: y_1 = A_1\left[a_{I1} m_{I1}^{-\rho_1} + a_{I2} m_{I2}^{-\rho_1}\right]^{-1/\rho_1} \qquad CES_2: y_2 = A_2\left[a_{II1} m_{II1}^{-\rho_2} + a_{II2} m_{II2}^{-\rho_2}\right]^{-1/\rho_2}$$

Fig. 4.2.: Scheme of a representative B-CHP production.
(Source: Authors' design).

4.3.3. Revenues

A B-CHP plant, by definition, produces both electricity $\Phi(y)$ and heat $\omega(y)$. Output levels depend on the amount of biogas *y* generated. In the following, the focus lies on CHP plants with an installed maximum electricity generating capacity of $\bar{\Phi}(y) = 500\,kw$.[17] The latter specifies overall combined output $F(y)$, including heat output $\omega(y)$ and losses $L(y)$, which results in the following general CHP output function:

$$F(y) = \Phi(y) + \omega(y) + L(y) \qquad (4.2.)$$

with $\alpha_1 F(y) = \Phi, \alpha_2 F(y) = \omega,$ and $\alpha_3 F(y) = L,$ where $\sum_{i=1}^{3} \alpha_i = 1$.

First of all, in order to assess revenues, the electricity and heat output of the CHP-plant must be determined. The relevant variables to provide information on the energy output are the energy content of biogas and the electrical and thermal efficiency as well as the percentage of loss, given technological restrictions. Energy output results from the product of daily biogas output. The latter contains a specific amount of energy which correlates directly with its methane content. The level of methane con-

[17] Naturally, this is a simplification. However, it does not cause a loss of generality regarding the model's applicability. Given certain minor alterations of the model setup, the use of different sizes of CHP plants can also be modeled likewise.

tent itself depends on the input factors used and varies between 50% to 75%. Since a cubic meter of Methane has an energy content of 10 kWh, the energy content of a cubic meter of biogas lies somewhere between 5 to 7,5 kWh (FNR 2012). Also, overall energy conversion efficiency of a B-CHP-system (regardless of the technical system chosen) is about 80-90%. So, at best, 90% of the supplied furnace's thermal capacity can be extracted (Weithäuser et al. 2010).
Hence, the following equation for the conversion of $m^3 BG$ to kWh can be determined:

$$1m^3 BG \approx \phi \, kwh \qquad (4.3.)$$

with ϕ being equal to the electrical, thermal or total energy conversion efficiency coefficient multiplied with the factor 10 to represent the energy content of a cubic meter of methane. These coefficients are in a range of 33 to 45% for electrical efficiency, 35 to 56% for thermal efficiency and, as mentioned above, 80 to 90% for total energy conversion efficiency (FNR 2012).
Regarding marginal revenue per unit of output, both the market prices for electricity and heat, as well as German FIT benefits need to be taken into account. Hence, marginal revenue for electricity generated, p^e, depends on a B-CHP's maximum capacity installed $\bar{F}(y)$, its actual output $F(y)$, as well as the kind of input factors, $\vec{m}_{ij}$,[18] used, as different benefit schemes apply depending on these plant and production characteristics. Hence, we have

$$p^e = p^e(\bar{\Phi}(y), \vec{m}_{ij}). \qquad (4.4.)$$

In case of heating, p^ω, there is generally a fixed compensation combined with a variable compensation depending on the overall heat production output level. Hence, we have

$$p^\omega = p^\omega(\bar{p} + p^v(\omega(y))). \qquad (4.5.)$$

Marginal revenue with respect to losses $L(y)$ is equal to zero. Also, remainders of B-CHP plant production, $R(y)$ might be sold or consumed, e.g. as fertilizers, generating a marginal revenue of p^r.

[18] For a detailed description of $\vec{m}_{ij}$ see section 4.3.4.

4.3.4. Costs

Costs, C, are mainly determined by input factor, $\vec{m}_{ij}$, use and their prices, $\vec{p}_{ij}$. In our model, input factor prices include per unit costs for cultivation, harvesting, transport and storage. This also reflects common practice, used by potential investors to assess variable costs of B-CHP energy production. The variable i defines the "Stoffklasse" (SK) – i.e. input factor category – of the respective input factor while j defines the specific kind of input factor – or subcategory (SUB) of SKi.

In addition to variable costs, there is a certain vector of fixed costs, c^F associated with the plant and cost of capital invested, which depends on its size, i.e. $c^F = \vec{c}_k(\Psi(y))$. Hence, we have

$$C = C(\vec{p}_{ij}, \vec{m}_{ij}, \vec{c}_k(\Psi(y))). \tag{4.6.}$$

4.3.5. Constraints

The most common constraints are either based on political restrictions, mainly specified in the German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz (EEG)) which defines the eligibility of the B-CHP plant for FIT benefits, or on technological factors. Most importantly, given the German FIT, some input substrates of SUB-SK $ij = I1$ must not exceed a certain percentage threshold, β, of total B-CHP input, i.e.

$$\beta \geq {m_{I1}} \Big/ {\sum_i \sum_j mij}.$$

This restriction concerns only corn, corn related substrates and crop within the German SK I and sets a limit of 60 mass percent for the mentioned substrates (BGBl 2011b).

Secondly, the usage of heat output must be above a certain percentage level, χ, in relation to total B-CHP heat output level, i.e. $\alpha_2 \geq \chi$. Given the status quo German FIT, α_2 is not to be below 0.25 in the first year of the entry into service and 0.60 in the following, in order for the plant to be eligible for benefits (BGBl 2011b).

As has already been mentioned in section 4.3.3., technological restrictions can occur concerning the use of different substrates in a B-CHP. In contrast, other findings suggest that a given substrate combination can be a useful device for hedging against fluctuations in both input factor costs and availability (Di Corato and Moretto

2011). However, although some B-CHP systems can (theoretically) be run with different substrate combinations, common practice shows that it is difficult to change fermentation technologies once adjusted to a certain input-mix (Eder and Kirchweger 2011). Consequently, we assume that a chosen substrate combination is retained throughout the B-CHP's lifecycle without any loss of generality.

4.3.6. Optimization Problem

In the following setup, a standard cost minimization program is conducted, given an exogenously given maximum installed capacity, which determined the desired B-CHP's output level $y = \bar{y}$, given both technological and regulatory constraints.[19]

<u>Cost Minimization</u>

Given equations (4.6.) and (4.1.) we have

$$\min_{\vec{m}_{ij}} C = C(\vec{p}_{ij}, \vec{m}_{ij}, \vec{c}_k(r)) \tag{4.7.}$$

s.t.

$$\bar{y} = y(A_i, \vec{a}_{ij}, \vec{m}_{ij}, \rho_i) \tag{4.8.}$$

as well as

$$\begin{aligned} &m_{I1} \le \beta \sum\nolimits_i \sum\nolimits_j m_{ij} \\ &\alpha_2 \ge \chi, \qquad \lambda_t \ge 0 \\ &i, j \in \{1,2\}. \end{aligned} \tag{4.9.}$$

The resulting first order conditions (FOC) require that the ratio of marginal products of the chosen input factors has to equal their price ratio, which, eventually, leads to the standard relationship (Chiang 1984) between the elasticity of substitution σ and the substitution parameter ρ, i.e.

$$\sigma_i = \frac{1}{1+\rho_i}. \tag{4.10.}$$

[19] A quick note on a possible conversion of our setup to a return on investment (ROI) approach: With respect to ROI, the standard approach is almost identical. It merely alters the function that is maximized to a certain but not necessarily very significant extent. It is defined as the percentage ratio of the profit's generated by the invested capital divided by its cost, i.e. the investment itself. Usually, there is a certain ROI target defined that the investment is expected to deliver. Hence, cost minimization as in equation (4.7.) remains unchanged and results are implemented given the standard ROI formula, i.e. $ROI = \Pi / K = [R - C] / K \ge \pi$ with K being total capital invested in the project and π being the desired level of return on investment.

In the course of our $n=\{1,2\}$ nested CES production function approach, we consider three different input factor combination cases. As small scale B-CHP plants are oftentimes installed by farmers, we use the following representative input factor combinations: Corn and Manure (*Case I*), Corn, Manure, and Grass (*Case II*), and Corn, Manure, Grass, and Sudangrass (*Case III*). In order to calculate the elasticity of substitution σ as well as production function parameter ρ, equation (4.10.) is calculated in combination with the following numbers. The latter are taken from the German biomass enactment (Biomasseverordnung) which can be found in the appendix of BGBl (2011b).

Corn	Manure	Grass	Sudangrass
324	45	45	113

Tab. 4.1.: Methane Content in m3 per t/FM.
(Source: Authors' design, based on BGBl 2011b).

The following table (**Tab. 4.2.**) illustrates our results:

Input Factor Combination	Setup	$\sigma, \sigma_1, \sigma_2$	$\rho, \rho_1, \rho_2, \gamma$
Case I: Corn/ Manure	$\min\limits_{m_{I1},m_{I2}} p_{I1}m_{I1} + p_{I2}m_{I2}$ s.t. $\bar{y} = A[a_{I1}m_{I1}^{(-\rho 1)} + a_{I2}m_{I2}^{(-\rho 1)}]^{(-1/\rho 1)}$ $\beta \geq [(m_{I1})/(m_{I1} + m_{I2})]$ $y = y(\bar{\Phi}) = \bar{y}$	$\sigma = 45/324$ $\approx 1/7,2$	$\rho \approx -0,861$
Case II: Corn/ Manure/ Grass	$\min\limits_{m_{I1},m_{III},m_{II2}} p_{I1}m_{I1} + p_{I2}m_{I2} + p_{III}m_{III}$ s.t. $y = A[a_{II}y_2^{-\rho 1} + a_{I1}m_{I1}^{-\rho 1}]^{(-1/\rho 1)}$ $y_2 = Dm_{III}^{\gamma}m_{II2}^{\gamma}$ $\beta \geq [(m_{I1})/(m_{I1} + m_{I2} + m_{III})]$ $y = y(\bar{\Phi})$	$\sigma_1 = 45/45$ $\approx 1/1$ $\sigma_2 = 90/324$ $\approx 1/3,6$	$\rho_1 \approx -0,722$ $\rho_2 \approx 0$ $\gamma \approx 0,5189$
Case III: Corn/ Manure/ Grass/ Sudan-grass	$\min\limits_{m_{I1},m_{I2},m_{III},m_{II2}} p_{I1}m_{I1} + p_{I2}m_{I2} + p_{III}m_{III} + p_{II2}m_{II2}$ s.t. $y = A[B(a_{I1}m_{I1}^{-\rho 1} + a_{I2}m_{I2}^{-\rho 1})^{-\rho/\rho 1} +$ $a_{II}\, y_2^{-\rho}]^{(-1/\rho)}$ $y_2 = Dm_{III}^{\gamma}m_{II2}^{\gamma}$ $\beta \geq [(m_{I1})/(m_{I1} + m_{I2} + m_{III} + m_{II2})]$ $y = y(\bar{\Phi})$	$\sigma = 90/437$ $\approx 1/5,41$ $\sigma_1 = 45/45$ $\approx 1/1$ $\sigma_2 = 113/324$ $\approx 1/2,86$	$\rho \approx -0,8151$ $\rho_1 \approx -0,65$ $\rho_2 \approx 0$ $\gamma \approx 0,5189$

Tab.4.2.: Calculation of the elasticity of substitution and production function parameter for the analyzed cases.
(Source: Authors' design, calculations by N. Wittmann with the help of Wolfram Mathematica).

With respect to Case II and III: Grass and Manure both yield approximately the same amount of m^3BG/tFM. Hence, the resulting elasticity of substitution equals one. Thus, the respective CES equals a generalized Cobb Douglas function (Chiang 1984).

4.3.7. Approximating the Production Function

The last step to generating our production functions is estimating the remaining parameters representing the underlying technology. This is accomplished in a two-step procedure. First, we generate a large number of random feasible input factor combinations for each Case I to III. Afterwards, we use an algorithm to identify the functional parameters that best represent our set of possible input factor combinations. The following table (**Tab. 4.3.**) shows our results:

Input Factor Combination	Parameters	Production Function[20]
Case I: Corn/ Manure	$A \rightarrow 302,645$ $a_{I1} \rightarrow 0,999$ $a_{I2} \rightarrow 0,181$	$\bar{y} = 2500 = 302,645$ $[0,999 m_{I1}^{0,861} + 0,181 m_{I2}^{0,861}]^{1/0,861}$
Case II: Corn/ Manure/ Grass	$A \rightarrow 281,3728$ $D \rightarrow 3,0532$ $a_{I1} \rightarrow 0,9909$ $a_{II} \rightarrow 0,2486$	$\bar{y} = 2500 = 281,3728$ $[0,2486(3,0532\, m_{II1}^{0,5189} m_{II2}^{0,5189})^{0,722}$ $+ 0,9909 m_{I1}^{0,722}]^{1/0,722}$
Case III: Corn/ Manure/ Grass/ Sudangrass	$A \rightarrow 260,51$ $B \rightarrow 0,9999$ $D \rightarrow 1,256$ $a_{I1} \rightarrow 0,9999$ $a_{I2} \rightarrow 0,44629$ $a_{II} \rightarrow 0,2965$	$\bar{y} = 2500 = 260,51$ $[0,9999\left[[0,9999 m_{I1}^{0,65} + 0,44629 m_{I2}^{0,65}]^{1/0,65}\right]^{0,815}$ $+ 0,2965\left[1,256 m_{II1}^{0,5189} m_{II2}^{0,5189}\right]^{0,815}]^{1/0,815}$

Tab. 4.3.: Approximation of CES production functions for the analyzed cases.
(Source: Authors' design, calculations by N. Wittmann with the help of Wolfram Mathematica).

Case I can be illustrated by the following graph (**Fig. 4.3.**). It depicts the variable cost function, given the input factor prices and the CES production function:

[20] Assuming a given average plant efficiency level of about 85%, we arrive at $\gamma\ m^3 BGh = (500 kwh / 2.4) / 0.85 \approx 248 BGh$ or rather $\gamma\ m^3 BGh = (500 kwh / 2) \approx 250 BGh$ which, per day (assuming an average of 10 operating hours) results in an output of about approximately $\bar{y} \approx 2500\, m^3 BG / day$.

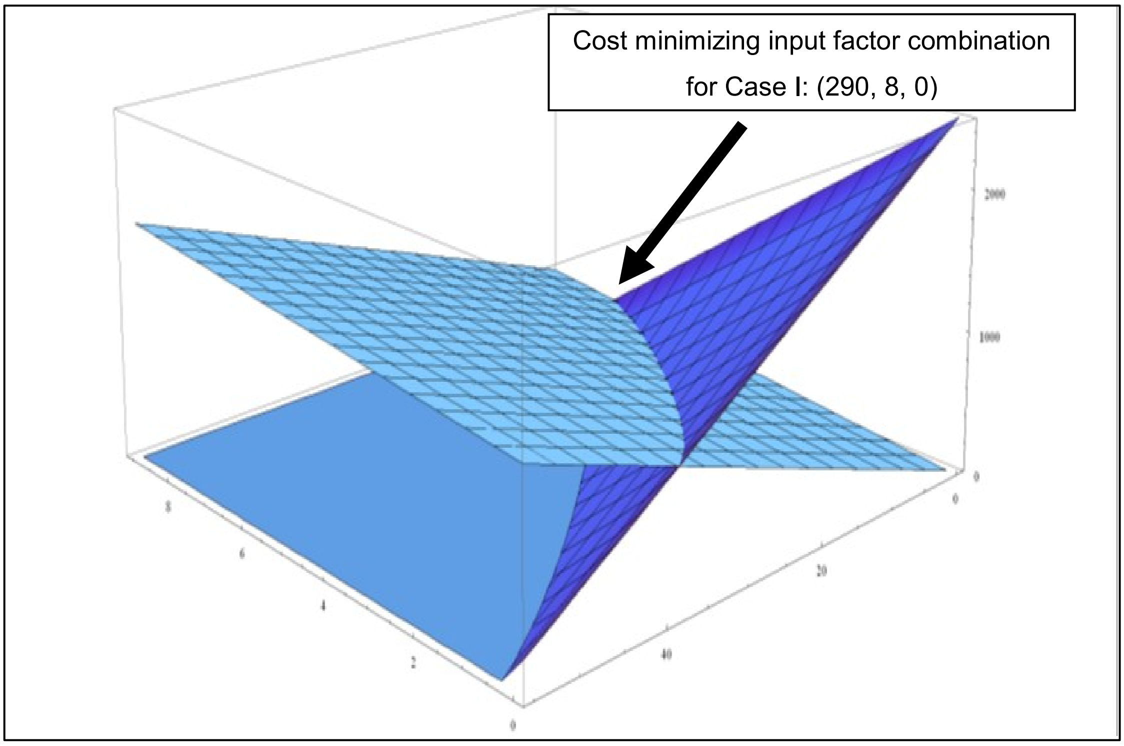

Fig. 4.3.: Graphical illustration of the cost minimizing input factor combination for Case I.
(Source: Authors' design, underlying calculations and graphical illustration by N. Wittmann with the help of Wolfram Mathematica).

The lowest point at which the two planes intersect represents the cost minimizing input factor combination with which the desired output level can be achieved. In the following section, results are presented for all relevant Cases I to III.

4.4. Numerical Illustration: Identifying Optimal Input Factor Combinations

In order to illustrate our model setup and its findings, three numerical examples are conducted in this section. As shown, e.g. by Eder and Kirchweger (2011), the majority of B-CHP plants already installed in 2009 were designed to operate using only two to four different input factors. We now use our previous findings to calculate the optimal input factor combinations both with and without regulatory constraints in each of our two to four input factor setups. Afterwards, we compare our results to real life examples and compare our results to the latter. For calculations, the following numbers are used:

Price per tFM Corn	Price per tFM Manure	Price per tFM Grass	Price per tFM Sudangrass	Corn input ratio restriction β.
35	25	40	45	$\beta_2 = 60\%$

Tab. 4.4.: Input prices of the input factors relevant for cases.
(Source: Authors' design, based on KTBL 2012).

The following table (**Tab. 4.5.**) illustrates cost minimizing input factor combinations and resulting costs:

	Case I / 2 Input Factor B-CHP	Case II / 3 Input Factor B-CHP	Case III / 4 Input Factor B-CHP
Cost minimizing input factor combination without regulation or restrictions on input factor capacity	Corn: $m_{I1} \approx 8$ Manure: $m_{I2} \approx 0,1$	Corn: $m_{I1} \approx 8$ Manure: $m_{I2} \approx 0,2$ Grass: $m_{II1} \approx 0,1$	Corn: $m_{I1} \approx 8$ Manure: $m_{I2} \approx 0,1$ Grass: $m_{II1} \approx 0,2$ Sudangrass: $m_{II2} \approx 0,1$
Related Costs I (RC I)	290	312	326
Cost minimizing input factor combination with regulation on corn ≤ 60% of total input	Corn: $m_{I1} \approx 7,1$ Manure: $m_{I2} \approx 4,8$	Corn: $m_{I1} \approx 6,7$ Manure: $m_{I2} = 3,3$ Grass: $m_{II1} = 1,1$	Corn: $m_{I1} \approx 6,1$ Manure: $m_{I2} = 3,7$ Grass: $m_{II1} \approx 0,25$ Sudangrass: $m_{II2} \approx 0,1$
RC II	370	371	375
∆ Cost increase due to corn constraint with respect to RC I	+80 ≈ +28%	+49 ≈ +16%	+49 ≈ +15%

Tab. 4.5.: Numerical results for the optimization of the analyzed cases.
(Source: Authors' design, calculations by N. Wittmann with the help of Wolfram Mathematica).

Our results clearly show that a restriction of the low-cost, high-methane-content input factor corn is necessary to ensure the usage of secondary resources such as manure. As corn yields an extremely high m^3 per *t/FM* methane output – i.e. 7.2 times the methane output of manure – at relatively low cost, it will always be the dominant input factor, in the absence of additional restrictions and constraints. Hence, any restrictions on corn input will certainly drive up costs, as long as all other input factor options come at a cost as well.

Furthermore, more input factors leads to more complex processes (logistically, technically, and chemically). Hence, from an intuitive viewpoint production costs should increase with the number of input factors. This intuition is confirmed by the numerical results of cost relationship without corn restriction (line RC I) as Case I < Case II < Case III. Once the input factor restriction on corn is imposed however, this causes the highest relative cost increase with respect to Case I. Intuitively speaking, if prices are volatile and prone to increase suddenly, a more diverse input factor portfolio is more stable in dealing with the resulting effects on aggregate production costs. Also, determining the cost increase due to the input factor constraint on corn allows for B-CHP owners to evaluate to what extent additional bonuses available within the German FIT system might cover the latter.

4.5. Conclusion

The analysis presented in the previous sections renders some valuable insight into the microeconomic aspects and variable cost drivers of small scale B-CHP plants. The formal approach chosen differs from those prominent in current scientific literature in various ways. On the one hand, a different microeconomic roadmap is used to conduct the analysis using nested CES production functions. Thereby, all relevant input factor costs and optimization constraints can be taken into account and the least cost input factor combination can be identified with respect to different production technologies available, e.g. Case I to III. Furthermore, the issue of accounting for the opportunity costs of seemingly costless input factors, such as manure, which is usually generated as a side product of other farming activities, is included in the analysis.

Further research might deal with various aspects such as analyzing scenarios regarding rising input factor prices. Also, including our cost minimization approach in an elaborate return-on-investment analysis might cater to investor’s needs. Finally, the

scope of our setup could be used as a valuable starting point to define B-CHPs' CO_2 reduction potential along the entire production chain.
Nonetheless, our approach in its current form presents a number of useful insights to policy makers. Estimating cost increases caused by input factor restrictions (see **Tab 4.5.** for the effects on total costs of a corn restriction) - may they be of economic or political nature -, aids policy makers in adjusting the underlying regulatory framework. Thereby, this could help to improve the design of energy policy measures to better achieve particular goals of environmental policy such as the promotion of low carbon input factor combinations in renewable energy generation.

4.6. Literature

Arrow, K.J./ Chenery, H.B./ Minhas, B.S./ Solow, R.M. (1961): Capital-labor substitution and economic efficiency. In: *The Review of Economics and Statistics*, 43 (3), 225-250.

Berndes, G./ Hansson, J. (2007): Bioenergy expansion in the EU: cost-effective climate change mitigation, employment creation and reduced dependency on imported fuels. In: *Energy Policy*, 35 (12), 5965-5979.

Bundesgesetzblatt (BGBl) (2011a): Dreizehntes Gesetz zur Änderung des Atomgesetzes – Vom 31. Juli 2011. Legislative text also available on the internet at the following address, URL: http://www.bgbl.de/Xaver/start.xav?startbk=Bundesanzeiger_BGBl&bk=Bundesanzeiger_BGBl&start=//*[@attr_id=%27bgbl111s1704.pdf%27 (last time accessed 11.10.2015).

Bundesgesetzblatt (BGBl) (2011b): Gesetz zur Neuregelung des Rechtsrahmens für die Förderung der Stromerzeug ung aus erneuerbaren Energien vom 28. Juli 2011 – Bundesgesetzblatt Jahrgang 2011 Teil I Nr. 42 S. 1634. Legislative text also available on the internet at the following address, URL: http://www.bgbl.de/xaver/bgbl/start.xav?start=//*[@attr_id=%27bgbl111s1633.pdf%27]#__bgbl__%2F%2F*[%40attr_id%3D%27bgbl111s1634.pdf%27]__1445347531561 (last time accessed 08.10.2015).

Bundesministerium für Wirtschaft und Technologie (BMWi)/ Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2010): *Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung*. BMWi/ BMU, Berlin, Germany, 2010.

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2012): *Erneuerbare Energien in Zahlen - Nationale und internationale Entwicklung*. BMU, Berlin, Germany, 2012.

Bräuninger, M./ Schulze, S. (2012): *Konsequenzen der Energiewende – Eine Studie des Hamburgischen Weltwirtschaftsinstituts (HWWI) im Auftrag der UniCredit Bank AG*. UniCredit Bank AG, München, Germany, 2012.

Chiang, A.C. (1984): *Fundamental Methods of mathematical Economics*. 3rd edition, McGraw-Hill, New York, NY, 1984.

Di Corato, L./ Moretto, M. (2011): Investing in biogas: Timing, technological choice and the value of flexibility from input mix. In: *Energy Economics*, 33 (6), 1186-1193.

Dong, L./ Liu, H./ Riffat, S. (2009): Development of small-scale and micro-scale biomass-fuelled CHP systems – A literature review. In: *Applied Thermal Engineering*, 29 (11), 2119-2126.

Eder, M./ Kirchweger, S. (2011). *Aufbereitung und Analyse von Daten aus dem Arbeitskreis Biogas zu Kosten bestehender Biogasanlagen – Studie im Auftrag des Amtes der Niederösterreichischen Landesregierung, der Wirtschaftskammer Niederösterreich und der Niederosterreichischen Landeslandwirtschaftskammer*. Universität für Bodenkultur Wien (BOKU), Vienna, Austria, 2011.

Erdmann, G. (2011): *Kosten des Ausbaus der erneuerbaren Energien - Eine Studie der Technischen Universität Berlin im Auftrag von vbw – Vereinigung der Bayerischen Wirtschaft e.V., Bayerische Chemieverbände, Bayerische Papierverbände, Verband der Bayerischen Energie- und Wasserwirtschaft e.V. – Stand Juli 2011*. vbw Vereinigung der Bayerischen Wirtschaft e.V., Munich, Germany, 2011.

Evans, R. (1993): Environmental and economic implications of small-scale CHP. In: *Energy Policy*, 21 (1), 79-91.

Fachagentur Nachwachsende Rohstoffe (FNR) (2012): *Basisdaten Bioenergie Deutschland*. FNR, Gülzow, Germany, 2012.

Gokcol, C./ Dursun, B./ Alboyaci, B./ Sunan, E. (2009): Importance of biomass energy as alternative to other sources in Turkey. In: *Energy Policy*, 37 (2), 424-431.

Goulding, D./ Power, N. (2013): Which is the preferable biogas utilisation technology for anaerobic digestion of agricultural crops in Ireland: Biogas to CHP or biomethane as a transport fuel?. In: *Renewable Energy*, 53, 121-131.

Hall, D.O. (1991): Biomass energy. In: *Energy Policy*, 19 (8), 711-737.

Kaphengst, T./ Umpfenbach, K. (2008): *Biogasnutzung im ländlichen Raum – Der Beitrag verschiedener Anlagenkonzepte zur regionalen Wertschöpfung und ihre Umweltleistung*. Ecologic Institute, Berlin, Germany, 2008.

Kemfert, C. (1998): Estimated substitution elasticities of a nested CES production function approach for Germany. In: *Energy Economics*, 20 (3), 249-264.

Kemfert, C./ Schäfer, D. (2012): Financing the Energy Transition in Times of Financial Market Instability. In: *DIW Economic Bulletin*, 2 (9), 3-13.

König, A. (2011): Cost efficient utilisation of biomass in the German energy system in the context of energy and environmental policies. In: *Energy Policy*, 39 (2), 628-636.

Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL) (2012): Wirtschaftlichkeitsrechner Biogas. URL: http://daten.ktbl.de/biogas/startseite.do (last time accessed 08.10.2015).

Madlener, R./ Schmid, C. (2003): Combined heat and power generation in liberalised markets and a carbon-constrained world. In: *GAIA-Ecological Perspectives for Science and Society*, 12 (2), 114-120.

McFadden, D. (1963): Constant elasticity of substitution production functions. In: *Review of Economic Studies*, 30 (2), 73-83.

Papageorgiou, C./ Saam, M. (2008): Two-level CES Production Technology in the Solow and Diamond Growth Models. In: *Scandinavian Journal of Economics*, 110 (1), 119-143.

Prywes, M. (1986): A nested CES approach to capital-energy substitution. In: *Energy Economics*, 8 (1), 22-28.

Rentizelas, A.A./ Tatsiopoulos, I.P. (2010): Locating a bioenergy facility using a hybrid optimization method. In: *International Journal of Production Economics*, 123 (1), 196-209.

Stürmer, B./ Schmid, E./ Eder, M. W. (2011): Impacts of biogas plant performance factors on total substrate costs. In: *Biomass and Bioenergy*, 35 (4), 1552-1560.

Toke, D./ Fragaki, A. (2008): Do liberalised electricity markets help or hinder CHP and district heating? The case of the UK. In: *Energy Policy*, 36 (4), 1448-1456.

Uzawa, H. (1962): Production functions with constant elasticities of substitution. In: *Review of Economic Studies*, 29 (4), 291-299.

Verbruggen, A./ Dufait, N./ Martens, A. (1993): Economic evaluation of independent CHP projects. In: *Energy policy*, 21 (4), 408-417.

Walla, C./ Schneeberger, W. (2008): The optimal size for biogas plants. In: Biomass and Bioenergy, 32 (6), 551-557.

Weithäuser, M./ Scholwin, F./ Fischer, E./ Grope, J./ Weidele, T/ Gattermann, H. (2010): *Gasaufbereitung und Verwertungsmöglichkeiten*. In: Fachagentur für Nachwachsende Rohstoffe (FNR) [ed.]: Leitfaden Biogas – Von der Gewinnung zur Nutzung. 5th edition, FNR, Gülzow, Germany, 2010.

Wickart, M./ Madlener, R. (2007): Optimal technology choice and investment timing: a stochastic model of industrial cogeneration vs. heat-only production. In: *Energy Economics*, 29 (4), 934-952.

Witt, J./ Thrän, D./ Rensberg, N./ Hennig, C./ Naumann, K./ Billig, E./ Sauter, P./ Daniel-Gromke, J./ Krautz, A./ Weiser, C./ Reinhold, G./ Graf, T. (2012): *Monitoring zur Wirkung des Erneuerbare-Energien-Gesetz (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse*. DBFZ, Leipzig, Germany, 2012.

Chapter 5: Economic Risk Analysis of Decentralized Renewable Energy Infrastructures – A Monte Carlo Simulation Approach

by

Prof. Dr. Uwe Arnold

Bauhaus-Universität Weimar

Department of Urban Infrastructure Management

and

Özgür Yildiz

Technische Universität Berlin

Department of Economic Policy and Environmental Economics

Journal article[21] published as:

Arnold, U./ Yildiz, Ö. (2015): Economic risk analysis of decentralized renewable energy infrastructures – A Monte Carlo Simulation approach. In: *Renewable Energy*, *77*, 227-239. http://dx.doi.org/10.1016/j.renene.2014.11.059.

Abstract

There are several different economic barriers such as high up-front capital costs, high transaction costs and diverse risks (e.g. performance and technical, contract risks, market risks) that keep potential investors or institutional lenders from investing in decentralized renewable energy technologies (RETs). Therefore, suitable business models, specific financing concepts and advanced risk management tools to deal with issues concerning transaction costs and financial risks are required to support RET investments.

This article deals with this issue by introducing a Monte Carlo Simulation (MCS) approach to risk analysis based on an entire life-cycle representation of RET-investment projects. By doing this, the authors uncover considerable advantages regarding content and methodology compared to ordinary NPV-estimation or sensitivity analysis. It could be shown that the presented financial analysis combined with MCS aids in optimizing the conceptual design of an investment project with respect to capital returns and risk. Since both issues are decisive for lenders and investors, the

[21] The style of the original paper was adapted in order to fit the formal style guidelines of this thesis.

double-criteria analysis method presented in this paper facilitates the raising of capital for project investments in decentralized RETs.

Keywords

Renewable energy technologies; Monte Carlo simulation; risk analysis; simulation applications; financial engineering; bioenergy

Acknowledgments

The authors would like to thank the German Federal Department of Education and Research (BMBF) for the funding of their research. This research was undertaken within the research project “RePro – Ressourcen vom Land” (support code: 033L008E) and was supported within BMBF-Funding Measure “Sustainable Land Management”.

Finally, the authors would also like to thank Prof. Dr. Kalogirou and the editorial board as well as the anonymous reviewers for valuable comments that helped improving the quality of our manuscript and Alexander C. Pusch (successful publishing) for language-editing.

List of abbreviations in chapter 5

BMBF	Bundesministerium für Bildung und Forschung/ Federal Ministry of Education and Research
C.A.R.M.E.N.	Centrales Agrar-Rohstoff Marketing- und Energie-Netzwerk e.V./ network for the commercialization of agricultural resources for energy use
DSCR	debt service cover ratio
EU	European Union
IRR	internal rate of return
MCS	Monte Carlo Simulation
MIRR	modified internal rate of return
NPV	net present value
pdf	probability density function
pdfs	probability density functions
RePro	RePro – Ressourcen vom Land
RET	renewable energy technology
RETs	renewable energy technologies
ROE	return on equity
ROI	return on investment

List of symbols in chapter 5

$CF_{tot,\tau}$	total cash flow (CF) in period τ including investment, operational, financing cash flows and the liquidation revenue for τ = T
$F_{NPV\leq 0}$	cumulated distribution function of negative NPVs
i_D	discount interest rate (measure of opportunity cost)
kWh	kilowatt hours
kW_{th}	kilowatt thermic
MW_{th}	megawatt thermic
μ	mean value
p	probability-value of a quantile
$pdf(\tilde{y})$	probability density function of the project NPV $\tilde{y}$
$pdf_i^{\alpha}(x_i)$	probability density function i of the input variable x_i
$pdf_j^{\omega}(y_j)$	probability density function j of the output variable y_j
$q(p)$	quantile value of a probability density function for probability *p* with $x_i < q$
R	financial project risk
$R_{NPV<0}$	cumulated risk of negative project NPV (product sum of negative NPVs and their probabilities)
S_i	specific curve representing sensitivity to variations of a related input parameter
σ	standard deviation
σ^2	variance = VAR(x_i)
$\hat{\sigma}$	standard deviation given a Log-normal distribution
T	number of balance periods (e.g. years)
x_i	random input variable of the deterministic project model (e.g. price of an input factor) with i = 1,2,3,…,n
y_j	model output variable (e.g. net present value) with j = 1,2,3,…,n
$\tilde{y}$	a projects NPV
$y_{NPV,0}$	net present value related to τ = 0
yr	year
ξ_k	a random number with *k* = 1,2,3,…,*n*

5.1. Introduction

A shift towards renewable energy sources characterizes economic and environmental policy measures in countries all over the world. Especially in the European Union (EU), ambitious goals for climate change mitigation have been set. According to this, mandatory national overall targets and measures for the use of energy from renewable sources are defined by the European Commission (Directive 2009/28/EC) to increase the share of renewable energy in the EU gross final consumption of energy to a minimum of 20% by 2020 (Jäger-Waldau et al. 2011).

Among other strategies pursued in most countries to reach this ambitious goal, decentralized, small scale renewable energy technologies (RETs) and the related energy production facilities, such as small scale bioenergy infrastructures, small scale wind farms and solar plants, are changing the structure and characteristics of the regional, national and even interconnected international energy supply infrastructures to an ever more rapidly growing extent. In spite of numerous benefits resulting from the implementation of RETs, e.g. their contribution to environmental protection, their impacts on economic growth by creating jobs, by forming human capital and by offering a market for new business models, several technical and economic barriers delay the implementation of RETs. Among these, financial obstacles play a particular role (Khan et al. 2014; Mudakkar et al. 2014; Mumtaz et al. 2014; Yildiz 2014).

First of all, RETs usually come with higher power-specific up-front capital costs than investments into conventional energy infrastructures. Furthermore, high transaction costs and other risks (e.g. performance and technical risks of the used technical facilities, contract risks with the suppliers of raw materials such as bioenergy crops, market risks such as future price developments and the impact of demographic changes to the local demand of energy) may hinder potential investors or institutional lenders to invest in RETs (Del Río 2007; Ringel 2003).

In general, capital costs are a function of the borrower's credit rating, the provided securities, the leverage ratio, and the aggregated project risk. Usually, higher aggregated project risk leads to higher interest rates requested for the loan or even to the complete loan denial by lenders such as banks. The spread of interest rates for higher risk investments is one of the direct consequences of the Second and Third Basel Accords of the international regulatory system for banking. Equity investors and institutional lenders link their return on investment (ROI)-expectations with project inherent risk. Thus, as in other domains of asset-financing, risk assessment and risk management are crucial prerequisites for financial feasibility of renewable energy projects.

Therefore, coping with financial constraints of renewable energy technology (RET)-investments requires a stable and reliable political and legal framework so potential investors can reduce regulatory risks and hence significantly reduce the cost of capital (Masini and Menichetti 20012). Moreover, suitable business models, specific financing concepts and advanced risk management to deal with transaction cost and financial risk issues (Wüstenhagen and Menichetti 2012) are required to support RET investments under undistorted market conditions (i.e. with gradually reduced subsidies and shrinking acceptance of public risk coverage for economic, technological or political reasons).

This article addresses the necessity of advanced risk management tools, and presents a Monte Carlo Simulation (MCS) approach to risk analysis based on a representation of the entire life-cycle of RET-investment projects. Therefore, this paper is structured as follows: Section two briefly describes characteristics of risk and risk management within the framework of RETs. Subsequently, the structure of the developed models and analysis tools, including MCS as a tool to evaluate the risk of an investment in RETs, are introduced and specified for the case of a wood heating plant. This basic introduction to the methodology of risk oriented financial analysis of investment projects is then demonstrated with an application case example of a planned project in Gräfenhainichen, Germany in section four. The paper closes with some concluding remarks and an outlook on future developments.

5.2. Risk analysis in decentralized renewable energy projects

Risk management of decentralized renewable energy projects consists of a sequence of different measures to identify, assess and allocate project risks. The aim of this procedural chain is to focus attention at potential factors that could have an impact on project cash flows, to analyze qualitatively and quantitatively the possible effects of an adverse event on project earnings and consequently on its viability, and finally to reduce risks by adopting appropriate measures within the project company or by delegating a specific risk to a third party. A minimum requirement an appropriate risk management system must fulfill from a lenders' point of view is the principle that the project should be able to cover debt service with its cash flows even in a worst-case scenario. Therefore, lenders resort to key figures such as the so called

debt service cover ratio (DSCR), which determines a projects capability to cover debt servicing from its cash flows, to evaluate a project. From an investor's perspective, the objective of risk management is to assure that the project is able to generate a proper return on equity in a base-case scenario which corresponds to the incorporated risk. For this purpose, fundamental key figures such as the internal rate of return (IRR) or the net present value (NPV), which convey a project's attractiveness to investors, are subject to risk analysis (Böttcher and Blattner 2010).
The individual risks which have an impact on a project's cash flow can be divided into different categories: Pre-completion phase risks, post-completion phase risks and issues common to both phases. Within the scope of pre-completion risks are primarily technical and construction risks whereas supply, operational and market risks constitute mainly post-completion risks. Risks arising from financial, legal, regulatory or environmental spheres build the group of risks common to both phases. Coping with these individual risks is achieved via various measures such as so called turnkey contracts for construction risks, take-or-pay and bring-or-pay agreements or other contractual agreements for market risks and e.g. insurance policies for environmental and operational risks, to name but a few (Gatti 2013). Nevertheless, risk positions stay relevant even with these measures so that there is a need for investors and lenders to assess the remaining entrepreneurial risk. Therefore, in the following a MCS approach is presented.

5.3. A Monte Carlo Simulation approach to risk analysis – the method and toolkit

So far, Monte Carlo techniques have rarely been used within the context of risk management of renewable energy infrastructures as they require considerable data processing and the definition of probability density functions for random input variables such as fuzzy or uncertain design and forecast parameters. Nevertheless, some examples exist such as MCS applications to wind energy (Gurgur and Jones 2010; Marmidis et al. 2008) or within the context bioethanol production (Amigun 2011).
The approach presented in this paper focuses on bio-energy infrastructures and analyzes the financial risk for investors and lenders by subjecting the NPV of bio-energy projects to an MCS. Prior to describing the methods chosen, some definitions are necessary.
The project-NPV $y_{NPV,0}$ is defined by equation (5.1.):

$$y_{NPV,0}(T, i_D) = \sum_{\tau=1}^{T} CF_{tot,\tau} \, (1 + i_D)^{-\tau} \quad (5.1.)$$

with

$y_{NPV,0}$: net present value related to $\tau = 0$

$CF_{tot,\tau}$: total cash flow (CF) in period τ including investment, operational, financing cash flows and the liquidation revenue for $\tau = T$

i_D : discount interest rate (measure of opportunity cost)

T : number of balance periods (e.g. years)

A zero-NPV indicates that investors receive complete repayment of the capital invested plus an appropriate interest according to the discount interest rate i_D. A negative NPV denotes that the investment cannot generate sufficient returns in order to compensate for opportunity costs. Positive NPV-values classify investment projects to be above average expectations of profitability. The investor expectations with respect to proper interest on equity are represented by the discount interest rate i_D which influences the NPV-value significantly and serves as an indicator of opportunity cost.

The NPV was chosen as a major comprehensive measure of financial feasibility and project profitability since it is easy to understand, convincing and practical, even for those (potential) project participants with little background in investment analysis (Johnson 1994). This accessibility is of particular importance within the financial analysis of decentralized renewable energy infrastructures where local stakeholders are often active drivers for the realization of infrastructure projects, but lack any investment analysis knowledge and therefore need practical tools to handle and overcome this constraint (Del Río and Burguillo 2008).

The financial project risk R of negative project NPVs may be defined as:

$$R_{NPV<0}(x_1 \dots x_n;\; i_D) = \int_{-\infty}^{0} pdf(\tilde{y}_{NPV,0}) \, d\tilde{y}_{NPV,0} \quad (5.2.)$$

with

$R_{NPV<0}$: cumulated risk of negative project NPV (product sum of negative NPVs and their probabilities)

$pdf(\tilde{y})$: probability density function (pdf) of the project NPV $\tilde{y}$

x_i : random input variable of the deterministic project model

Equation (5.2.) implies that the probability density function of the project-NPV $pdf(\tilde{y})$ is available. For this purpose, MCS is applied.

5.3.1. Methodological principles of Monte Carlo Simulation

MCS is a state-of-the-art methodology in risk analysis and finance (Hertz 1964; Alfen et al. 2010). The following figure (**Fig. 5.1.**) illustrates the operating principle of MCS:

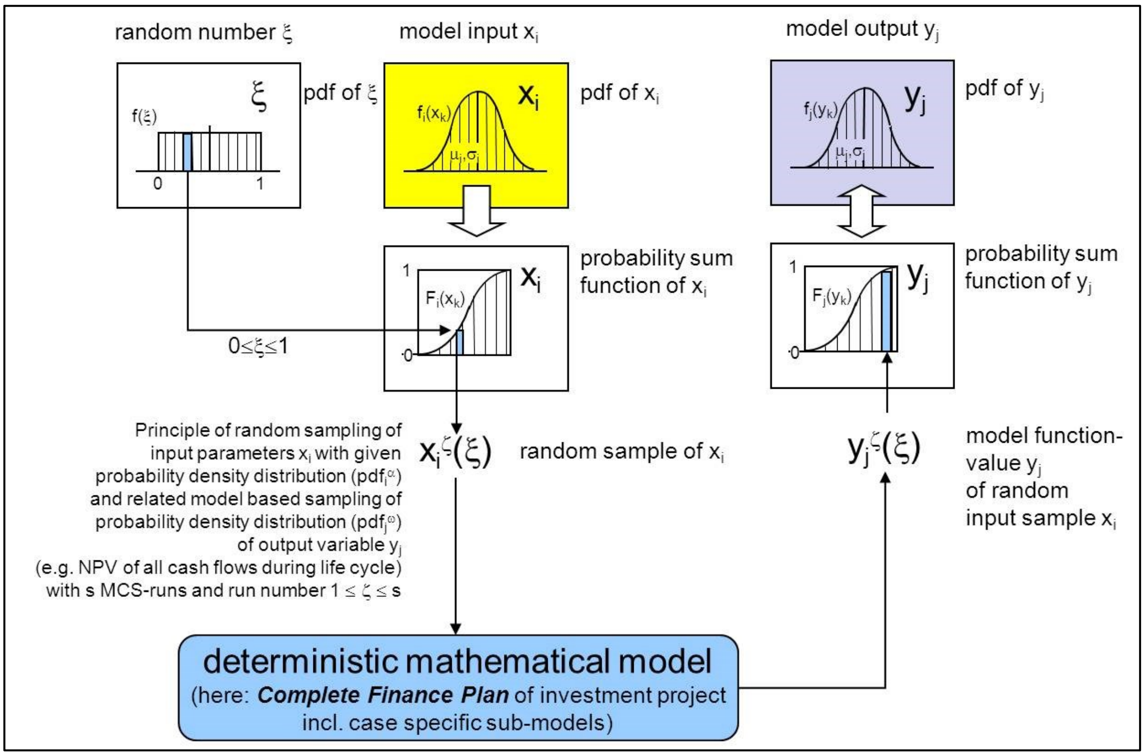

Fig. 5.1.: Operating principle of a Monte Carlo Simulation.
(Source: authors' design, based on Hertz 1964; Alfen et al. 2010).

Like a shell around a given deterministic model of the system to be analyzed (here: investment project), an MCS for risk analysis uses random numbers (or pseudo-random numbers) to select random samples of the required model input data x_i with given probability density functions (pdf) $pdf_i^{\alpha}(x_i)$ and carries out a large number of simulations in order to generate values for model output variables y_j over and over.

This repetition procedure gradually leads to a distribution of y_j-values which can be analyzed and transformed into probability density functions $pdf_j{}^{\omega}(y_j)$.

For a correct application of the MCS the input variables need to be considered as independent random quantities, i.e. they have to be completely uncorrelated. A purely random sampling of values from input-pdfs which are not completely independent of each other would lead to simulation errors and problems in the interpretation for risk analysis. However, if interdependencies between two input quantities exist, standardizing one input variable by the other can be used to decouple the two. For instance, instead of picking random samples for the variables inflation rate (consumer price index), annual rise of labor cost, annual rise of fuel cost etc., which are clearly correlated, the inflation rate and the inflation rate related excess quantities (difference between increase rate of a specific factor cost and the inflation rate) of the other model relevant cost dynamics parameters were used as random variables x_i as MCS input.

Sampling from the input pdfs is carried out in principle by using a random number generator which is provided by many standard computational tools (e.g. EXCEL). The random numbers ξ_k, (k = 1,2,3 … n) applied by the Monte Carlo method vary uniformly in the interval [0;1] which is the same interval as that of the standardized cumulative distribution function $F_i(x_i)$ of the model input variables x_i. Thus, the inverse function $F^{-1}(\xi)$ provides a sample of x_i. This procedure is applied separately to each of the different x_i in order to provide an input data set to the deterministic model of the system to be investigated (e.g. capital value calculation of an investment project). The model provides the interesting set of resulting quantities y_j which represent the corresponding sample set on the model output side.

Numerously repeated runs (>1000) of the previous sequence of steps create collections of random samples for each of the interesting output parameters which can be described by their pdfs and statistical properties (mean value, standard deviation etc.) as well.

5.3.1.1. Determination of probability density functions of MCS input variables

The crucial step of MCS, however, consists in the determination of the required probability density functions for the random input parameters x_i. The (input-) pdfs of the random model input variables x_i must be already known in order to apply a Monte Carlo Simulation as described. If a data based statistical derivation of the required

$pdf_i^{\alpha}(x_i)$ is not possible due to the lack of suitable data, a knowledge based empirical approximation should be used instead. In the application cases presented within this paper, the $pdf_i^{\alpha}(x_i)$-derivation procedure, which is illustrated in **Fig. 5.2.**, was applied.

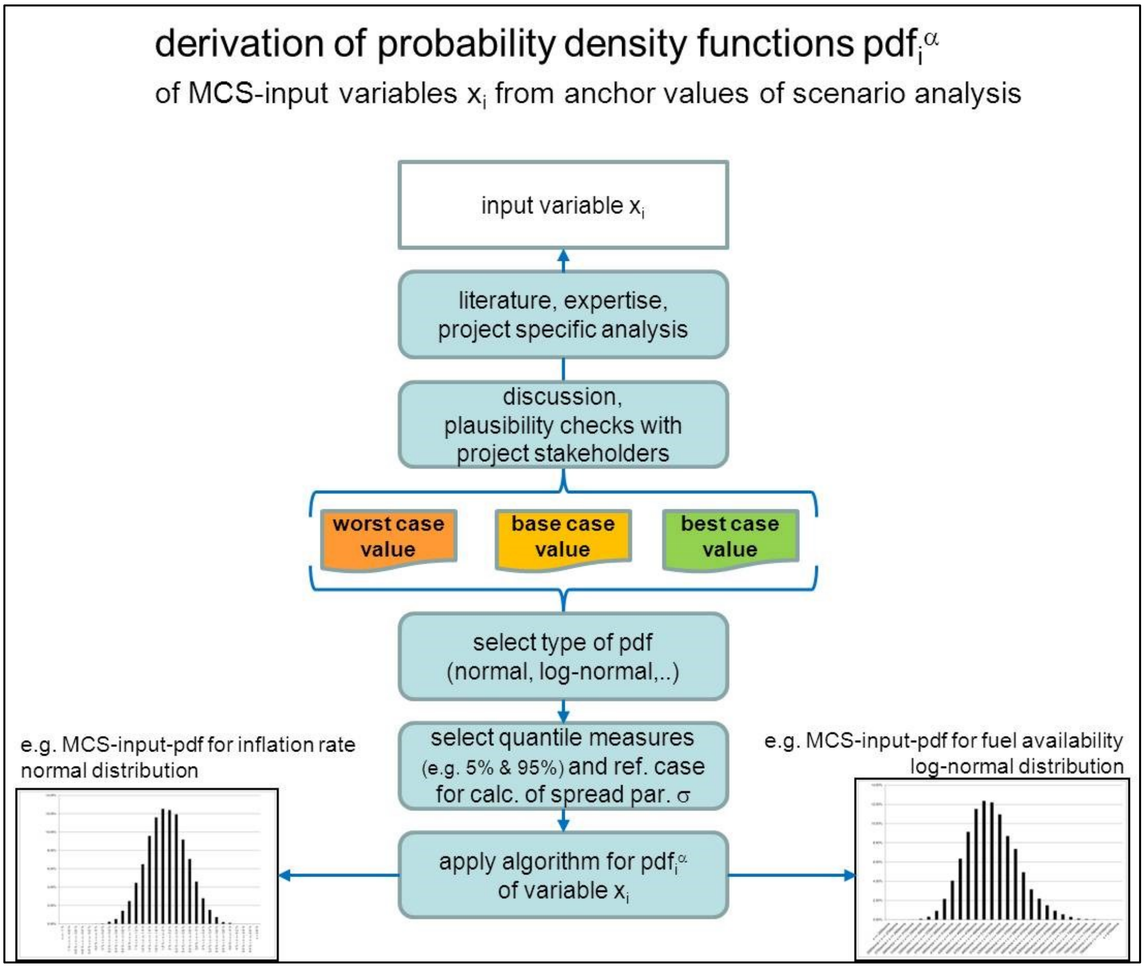

Fig. 5.2.: Derivation of probability density functions pdf_i^{α} of MCS-input variables x_i from anchor values of scenario analysis.
(Source: Authors' design, based on Hertz 1964; Alfen et al. 2010).

For each of the MCS-relevant input quantities x_i a first analysis is carried out based upon literature, reference cases and expert interviews revealing variation ranges of the input quantities of interest. Afterwards, the input values x_i are discussed in a workshop with the stakeholders involved in the project in order to determine plausible worst case, base case, and best case estimates. Usually, practitioners have sufficient experience and significant intuition to specify confidence intervals [worst case value; best case value] for each single input quantity. These empirical values of the random input quantities can be interpreted as quantiles $q(p)$ of a probability density function. Based upon these quantile-values, a specification of the type of the distribution (normal, log-normal) and of the corresponding probability-value p of the quantile, the $pdf_i^{\alpha}(x_i)$ can be calculated by means of the following equations:

5.3.1.1.1. Normal distribution

probability density function $pdf_i^{\alpha}(x_i)$:

$$f(x_i) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \tag{5.3.}$$

cumulative distribution function:

$$F(x_i) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x_i} e^{-(\xi-\mu)^2/2\sigma^2}\, d\xi \tag{5.4.}$$

with

μ:	mean value, here $\mu = E(x_i)$ as corresponding expectation value
σ:	standard deviation
σ^2:	variance = VAR(x_i)

σ from quantile $q(p)$:

$$\sigma = \left|\frac{q(p)-\mu}{\Phi_{sn}{}^{-1}(p)}\right| \tag{5.5.}$$

with

$q(p)$:	quantile value for probability *p* with $x_i < q$
$\Phi^{-1}(p)$:	inverse function of $\mathrm{f}(x)$ for standard normal distribution

leading to

$$\Phi_{sn}{}^{-1}(p) = \sqrt{-2\ln(p\sqrt{2\pi})} \tag{5.6.}$$

Using the base case value of x_i as the expectation value $E(x_i)$, selecting one of the extreme values (worst case or best case) as the quantile value $q(p)$ and specifying the related probability p (e.g. 5% or 95%) leads to the standard deviation σ.

5.3.1.1.2. Log-normal distribution

probability density function $pdf_i^{\alpha}(x_i)$:

$$f_{log}(x_i) = \frac{1}{x_i\sigma\sqrt{2\pi}} e^{-(lnx_i-\mu)^2/2\sigma^2} \text{ ; } x_i > 0 \qquad (5.7.)$$

cumulative distribution function:

$$F_{log}(x_i) = \int_{-\infty}^{x_i} \frac{1}{x_i\sigma\sqrt{2\pi}} e^{-(ln\xi-\mu)^2/2\sigma^2}\, d\xi \qquad (5.8.)$$

with:

$E(x_i)$: mean value, here with

$$E(x_i) = e^{\mu+\sigma^2/2} \qquad (5.9.)$$

as corresponding expectation value and

μ : $\mu = ln[E(x_i)] - \sigma^2/2$

$\hat{\sigma}$: $\hat{\sigma} = e^{\mu+\sigma^2/2}\sqrt{e^{\sigma^2} - 1}$;

As standard deviation given a Log-normal distribution with

σ from quantile q:

for ln(x) ≤ μ: $$\sigma = \left|\frac{ln\, q(p)-\mu}{\Phi_{sn}{}^{-1}(p)}\right| \qquad (5.10.)$$

and

for ln(x) > μ: $$\sigma = \left|\frac{ln\, q(p)-\mu}{\Phi_{sn}{}^{-1}(1-p)}\right| \qquad (5.11)$$

Using the base case value of x_i for $E(x_i)$, selecting one of the extreme values (worst case or best case) as the quantile value $q(p)$ and specifying the related probability p (e.g. percentiles 5% or 95%) leads to μ and σ by means of the iterative solution of the equations system (5.9.), (5.10.) and (5.11.) (for more details see Cook 2010).

The decision whether to select a normal or a log-normal distribution type for the input variable x_i is facilitated by the answer to the question whether negative values of x_i can occur. In many cases where negative values of x_i are not possible the log-normal distribution type is more appropriate than that of a normal distribution.

5.3.1.2. Selection of random MCS-input variables from sensitivity analysis

Both, the iterative determination of MCS-input pdfs and the MCS-sequence itself, create significant computational processing effort which is a function of the number of random input variables x_i. Therefore, with respect to computation time economics in practical applications, it makes sense to constrain the number of MCS-input variables x_i to those with the highest impact on the model-output y_j. Prior to carrying out the MCS-analysis, a sensitivity analysis of the deterministic model is used to rank the model input parameters x_i according to their relevance for the sensitivity of the model $|\partial y_j/\partial x_i|$. Figure 5.3. (**Fig. 5.3.**) illustrates a characteristic result of the sensitivity analysis carried out for the deterministic model of the wood-based bio-energy plant described in chapter 5.4.

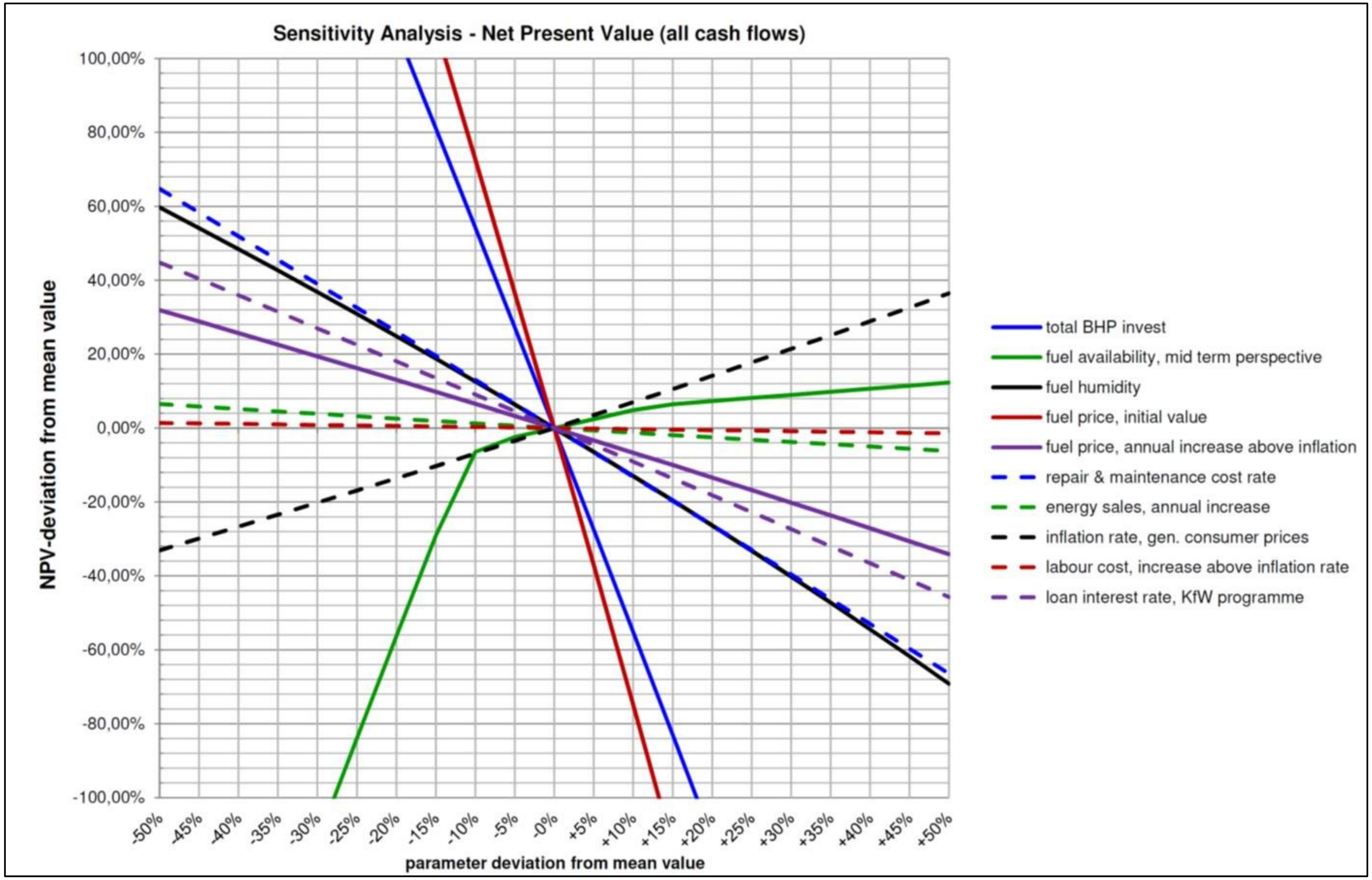

Fig. 5.3.: Exemplary result of a sensitivity analysis of the deterministic model.

(Source: Authors' design, underlying calculations and graphical illustration by U. Arnold with the help of MS EXCEL 2010).

Within the sensitivity analysis of the deterministic model, a single input parameter is varied systematically within a predefined range of values $[x_{i,min}; x_{i,max}]$. All the other input variables $x_{k \neq i}$ are kept constant with their base-case value. The related deviations of the model-output variables of interest y_j (here: project NPV) from its base-case value are recorded generating a sensitivity characteristic of the model $y_j/\bar{y}_j = S_i(x_i/\bar{x}_i)$ as displayed in **Fig. 5.3.** High gradients of the different characteristic curves S_i in **Fig. 5.3.** indicate high model sensitivity to variations of the related input parameter. In the example of Fig. 5.3., for instance, the standardized model sensitivity to small relative changes of “fuel price”, “total plant investment”, “repair & maintenance cost rate” and “fuel humidity” is above average with $\left|\partial(\frac{y_j}{\bar{y}_j})/\partial(\frac{x_i}{\bar{x}_i})\right|$ > 1.

5.3.1.3. MCS-output: financial risk indicators

The application of the MCS provides detailed insight into the probability distribution of the target variable (here: project NPV). In concrete terms, features such as the mean value or the median, left-, right- or two-sided confidence intervals, and the cumulative risk of negative values (insufficient return on equity (ROE) or even equity loss) can be calculated (see **Fig. 5.4.**). This analytically generated information helps potential investors and lenders to grasp the inherent risk of an investment and to expand the possibilities of plant and project design optimization.

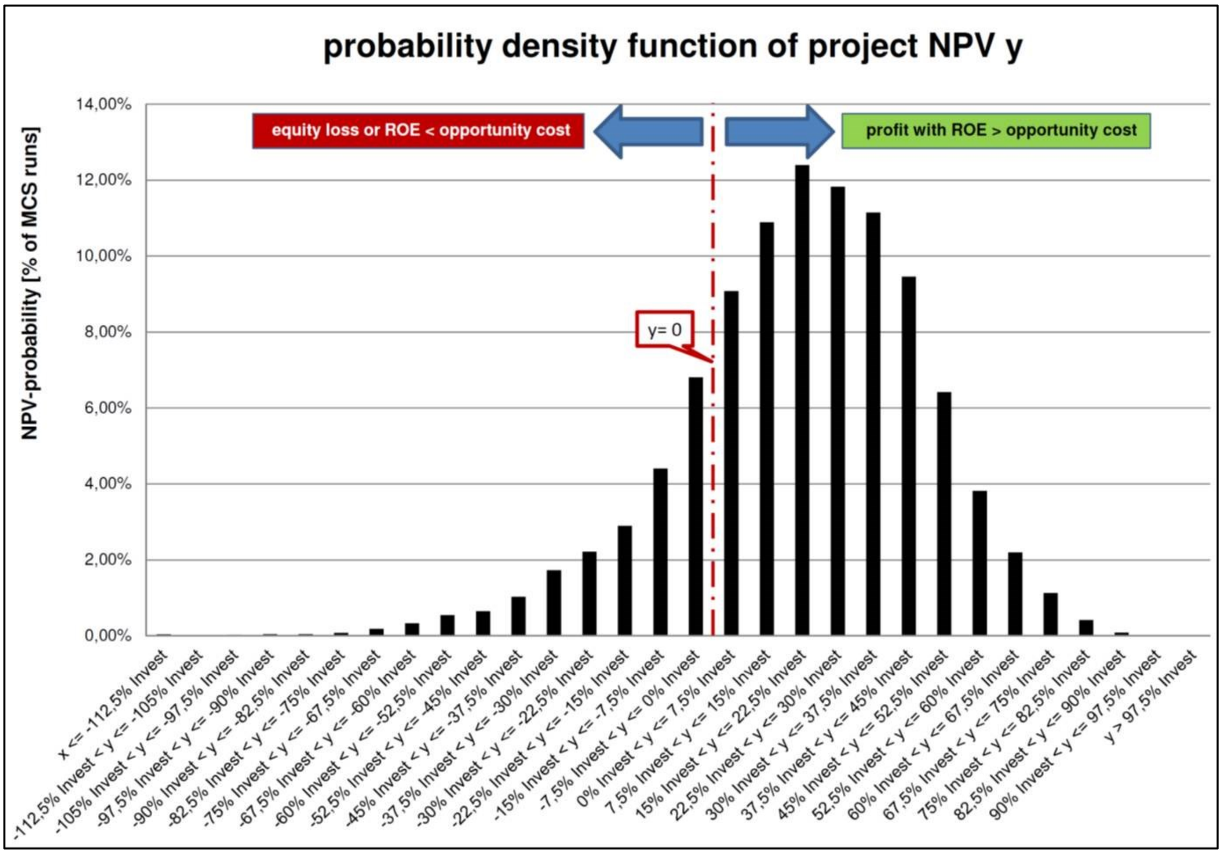

Fig. 5.4.: Exemplary MCS-results.
(Source: Authors' design, underlying calculations and graphical illustration by U. Arnold with the help of MS EXCEL 2010).

Fig. 5.4. displays the probability density function $pdf(y_{NPV,0})$ of the project-NPV as a histogram and shows the portions of the NPV-distribution below and above the discriminating value of y_{NPV} = 0. The area to the left of the y_{NPV} = 0 line represents the financial risk $R_{NPV<0}(x_1 \dots x_n;\ i_D)$ of negative project-NPVs according to equation (5.2.). The goal of a multiobjective risk-oriented optimization of the investment project consists in minimizing *R* and maximizing the mean value of y_{NPV}.

5.3.2. Architecture of the simulation model

The core of the model system (deterministic mathematical model in **Fig. 5.1.**) consists of a generic dynamic business plan ("complete finance plan") which can be applied to companies, profit centers and investment projects of any kind as well. It consists of a time series stack of the standard financial accounting statements (balance sheet, income statement, cash flow statement) in combination with compatible planning sheets of financing transactions. The individual accounting statement sheets are linked both horizontally in time with a time span of up to 50 periods and vertically along related financial quantities of revenues and cost, income flows and payments. Up to 20 profit centers or investment components (here: individual "projects") can be represented and activated separately and in any desired combination. The site, technology and case specific value creation processes, i.e. the dynamic development of revenues and cost in each "project" as a function of an unlimited number of input and boundary variables, are simulated in separate project specific calculation sheets ("project specific sub-models") including separate calculations of e.g. price index developments, material properties and sub-period operation schemes to mention just a few. The core model and its case specific sub-models are embedded in multiple operation shells for sensitivity analysis and MCS. A so-called "model cockpit" allows for parameter input, model control and displays the main results (NPV, IRR, sensitivity analysis and MCS results). **Fig. 5.5.** illustrates the functional architecture of the simulation model just described.[22]

[22] The simulation tool is a self-developed software application of Uwe Arnold and AHP Company. It was coded in Microsoft EXCEL 2010 with extensive use of the data table features of EXCEL for sensitivity analysis and MCS.

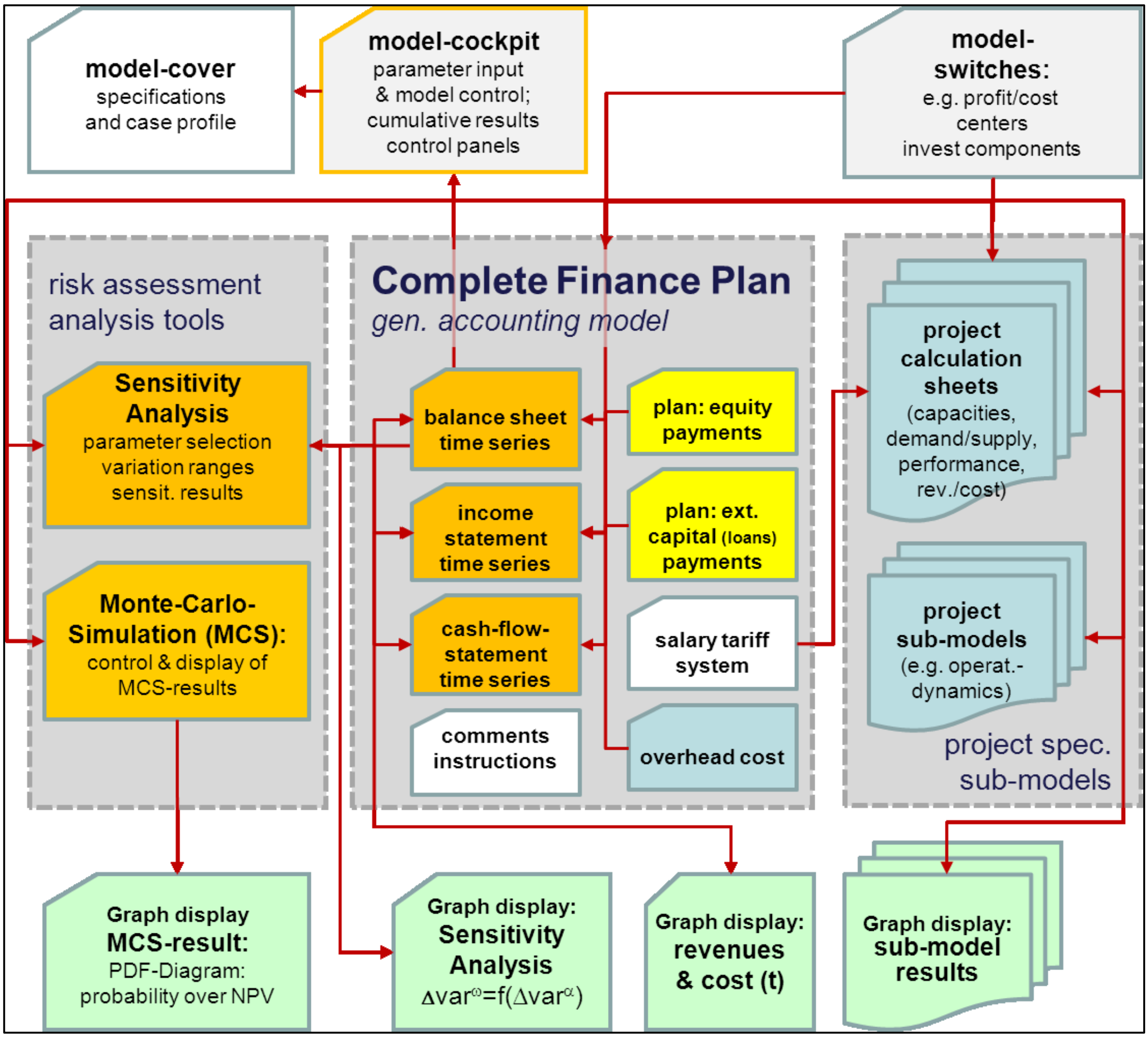

Fig. 5.5.: Model architecture and computational implementation.
(Source: Authors' design).

5.4. Application case: woodchip fired heating plant

In 2012 the methodology and computational toolkit as described in section three were applied to the financial analysis of a planned woodchip fired heating plant in Gräfenhainichen, in the state of Sachsen-Anhalt in Eastern Germany. This bio-energy investment project was part of the larger research project "RePro – Ressourcen vom Land" (RePro), which dealt with the identification and promotion of regional RET based value-added chains in order to support the economic structure in off-metropolitan areas. Special attention was devoted to regional stakeholder collaboration and to the realization of (small scale) decentralized resource and energy supply chains. Background, goals, investigations, projects and findings of RePro, which was funded by the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) are described in RePro (2013).

5.4.1. Application case features, initial and boundary conditions

Figure 5.6. (**Fig. 5.6.**) schematically illustrates the application case, the system components involved, and the value-added chain starting at regional forestry with the production of residual wood chips, proceeding in a heating plant with three alternative furnace and boiler lines and finally reaching the end-consumers of heat energy in a district heat network.

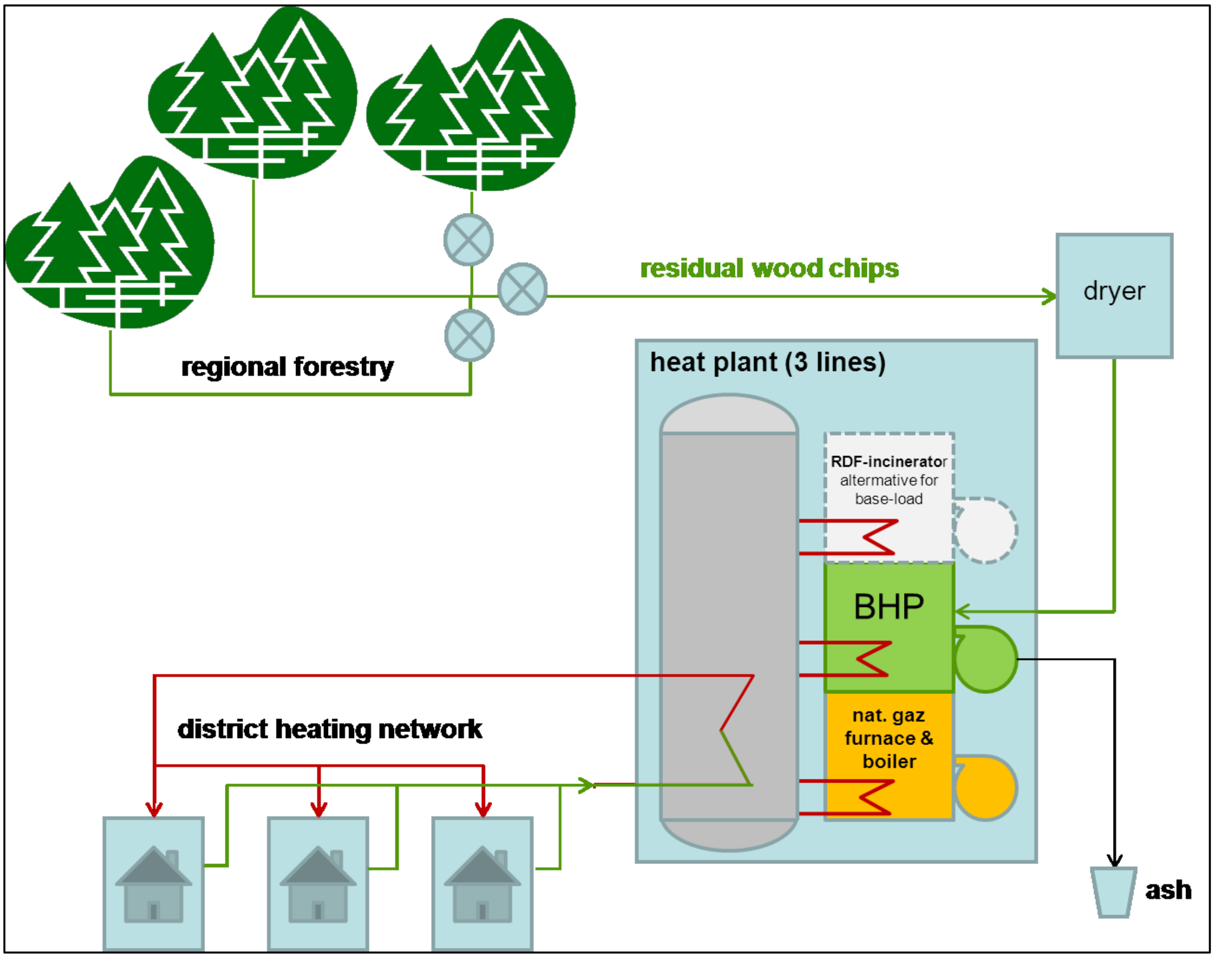

Fig. 5.6.: Application case: biomass heating plant, principle scheme of plant components, mass and heat flow.
(Source: Authors' design).

The involved stakeholder community of the project consists of the regional forestry cooperative, the local operating company of the heat plant and district heating network, which is a public private partnership of the municipality and a large energy utility, the public housing cooperative and the municipality itself. The existing heating infrastructure is structured into a heating plant with two natural gas fueled boiler units (total nominal power: 8.4 MW_{th}), two combined heat and power (CHP) units based upon palm oil (total nominal power: 464 kW_{th}), which were taken out of service due to cost and technical problems, and a district heating network of about 6 MW_{th} connected heat demand in 1000 apartments, three schools and a municipal indoor aquatic center. As a result of the RePro-activities the stakeholder community considered installing an additional biomass heating unit (wood chip furnace and boiler) in order to cover the annual base load of heating demand from residual wood output of the regional forestry. Among the goals of the project were stabilization of the local heat prices and increase of service safety for the end consumers (due to partial independence from the natural gas market dynamics), increase of local value creation, and reduction of the carbon footprint by means of partial RET application. A conceptual option of the change project consisted in the re-engineering and reactivation of the CHP units for residual oil and liquid biowaste incineration. Within the scope of the related financial analysis were the tasks of investigating the financial feasibility of the initially planned system configuration and the stepwise optimization of the design features with respect to efficiency and risk.

5.4.2. Preliminary problem analysis

Among the factors which determine project costs and earnings are the plant capacity, technical features and related total investment effort, the financing conditions, capital costs as a function of asset value, depreciation, and financing costs, the varying heat demand of end-consumers, corresponding energy outputs of the plant, corresponding utilization of the plant capacity, fuel, operation and overhead cost.

The estimation of heat demand development requires information on the local population (and other heat consumers) such as demographic forecasts and information on factors influencing their respective heat consumption, i.e. building and housing characteristics, other technical features, and climate factors (Schuler et al. 2000). In principle, due to the demographic and climate change effects in the medium term perspective of several decades a decline is more to be expected than an increase of the annual average heat demands especially for rural or off-metropolitan project regions of Central Europe.

A cost factor of major importance for a wood-based bio-energy plant (identified by carrying out a sensitivity analysis, see **Fig. 5.3.** for an example) is the fuel price, here

the price of woodchip. The woodchip price per stere mainly depends on woodchip quality determined by its humidity ratio and on transport costs which depend on the distance of transport from harvest zone to drying facility and from there to the incineration plant. Especially operators of smaller heating plants have to cope with higher resource prices per stere since larger plants above 5 MW_{th} nominal power can admix woodchips of lower quality without performance losses (Zormaier and Schardt 2007). In order to forecast the woodchip price development, a regression analysis based on past woodchip prices recorded nationally by the C.A.R.M.E.N. network (C.A.R.M.E.N. 2013) was carried out. In 2011 for instance, the annual rise of national mean values of the woodchip prices in the quality class of 35% humidity was approximately 6.7%/yr, in earlier phases even higher relative growth rates could be observed, reaching 13%/yr. This example indicates a significant difference between the fuel price developments and other indicators of price inflation such as general consumer or producer price indices. Thus, the fuel price development over time should be accounted for separately in financial analysis and cannot be covered sufficiently well with the average inflation rate.
Apart from the fuel price, the dynamic development of fuel availability in stere woodchips per year is another decisive parameter since it constrains the nominal incinerator and boiler capacity if more or less continuous plant operation is desired. The area specific amount of woodchip volume production from forestry can be estimated roughly by the heuristic value of 3 steres per hectare and year providing the required forestry catchment area for a given annual demand of woodchip volume (and a given nominal boiler power). However, increasing the woodchip catchment area of a woodchip heating plant – e.g. by means of additional supply contracts with forestry operators from more distant regions – not only increases the available fuel volume but also the average transport distance and the related cost. Thus, the economically reasonable amount of available woodchip fuel for a specific plant site should be derived in a multi-step process according to the regional distances and market conditions.
Of course, plant technology also has an impact on economic efficiency. Regarding power specific investment cost, it makes sense to use “off-the-shelf” market established furnace/boiler units instead of an individually designed and manufactured (customized) plant. State-of-the-art products of established manufacturers show sufficient operational power elasticity to be operated with close to maximum efficiency even far below their nominal power capacity. Figure 5.7. (**Fig. 5.7.**) illustrates the high elastici-

ty of combustion efficiency for market available standard woodchip furnace/boiler units. The thermal power of the unit can be reduced to 40% of the nominal thermal capacity without any significant loss of combustion efficiency. Thus, there is a relatively wide operating range for adapting the thermal output of a woodchip based heating plant to varying heat demand and fuel availability conditions.

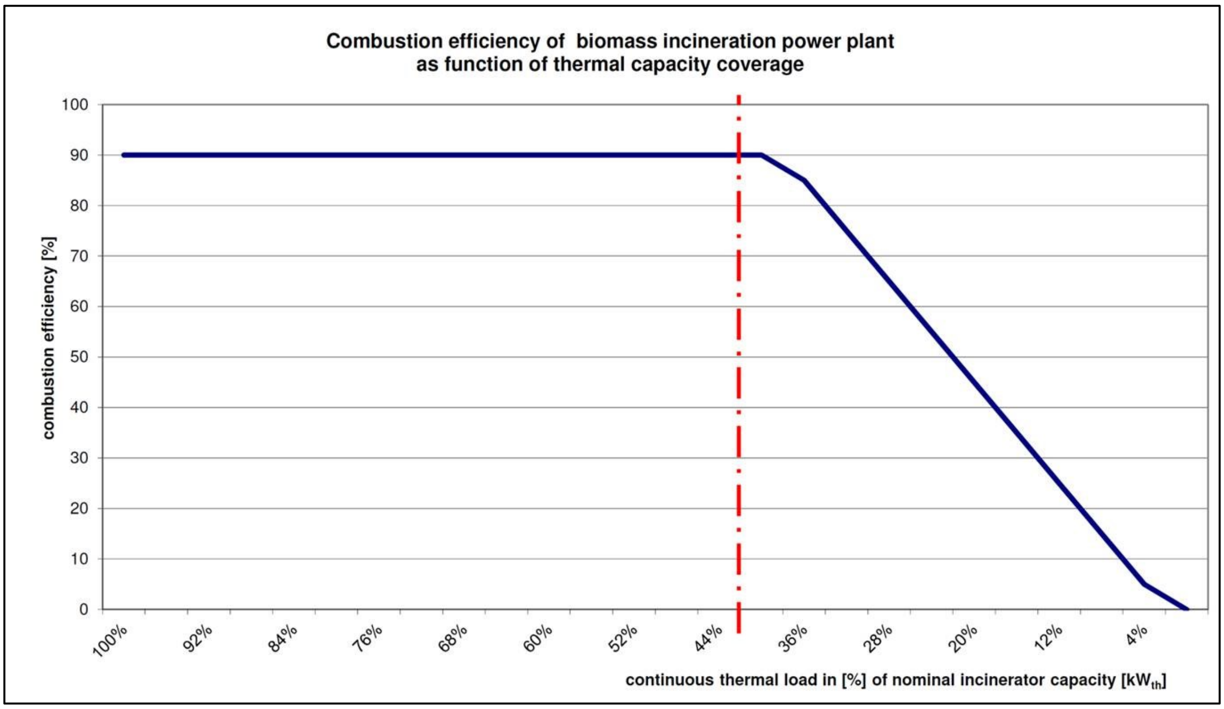

Fig. 5.7.: Combustion efficiency characteristics of a typical woodchip furnace/boiler unit.
(Source: Authors' design, underlying calculations and graphical illustration by U. Arnold with the help of MS EXCEL 2010).

The existing heat tariff system for end-consumers consists of two components, a basic charge which reflects the price of reserving a specific connected power capacity in kW and a working price for the effectively consumed heat energy in kWh.
In total 54 different input-variables were identified in the preliminary problem analysis to be relevant for the financial analysis of the woodchip heat plant project. Most of these parameters are uncertain or fuzzy and showed significant variation of their empirical values provided by literature or expert interviews. These parameters can be structured into the following groups:

- Financing specifications
- Investment specifications
- Sales and revenue specifications

- Fuel (raw material) specifications
- Operation cost specifications
- Tax specifications
- Price dynamics parameters

5.4.3. Case specific sub-models of the complete finance plan

The value creation process of the planned woodchip fired heating plant component and the functional relations between cost and revenue quantities and the 54 fuzzy input variables mentioned above were mathematically represented in a sub-model (stack of spreadsheet tables, see **Fig. 5.5.**). The underlying assumption is that of a separate operating company or profit center for the woodchip fired heating plant. Revenues from heat sales to the district heat network and end-consumers were calculated according to the existing heat tariff system. Heat price propagation over time, however, was based on the consumer price index in order to meet the stakeholders' expectations of a project contribution to price stabilization and attenuation of the natural gas market volatility.

Due to the case specific importance of the relations between heat production, fuel availability, heat demand and furnace/boiler elasticity an additional sub-model had to be implemented for determining the sub-period plant operation scheme of each single year. The following assumptions were made: During a single year of operation the plant is used for base-load coverage of the annual heat demand which follows a seasonal modulation. Thus the plant is operated between its maximum power and the marginal power level below which the combustion efficiency significantly shrinks (here: 40% of the nominal power). If the heat output falls below the marginal level, the plant is shut down. Furthermore, the plant is shut down during summer for a variable revision period and if the available annual fuel amount in storage is completely consumed. If less than the required annual fuel amount is available, the plant will be operated at maximum possible power level according to actual heat demands between January and the date when the fuel stock is completely spent. Thus, the annual plant operation scheme may change over the single years of the project life-cycle because of changing heat demands (demography, climate) and fuel availability (contracts, forestry operation). Figure 5.8. (**Fig. 5.8.**) illustrates the annual plant operation.

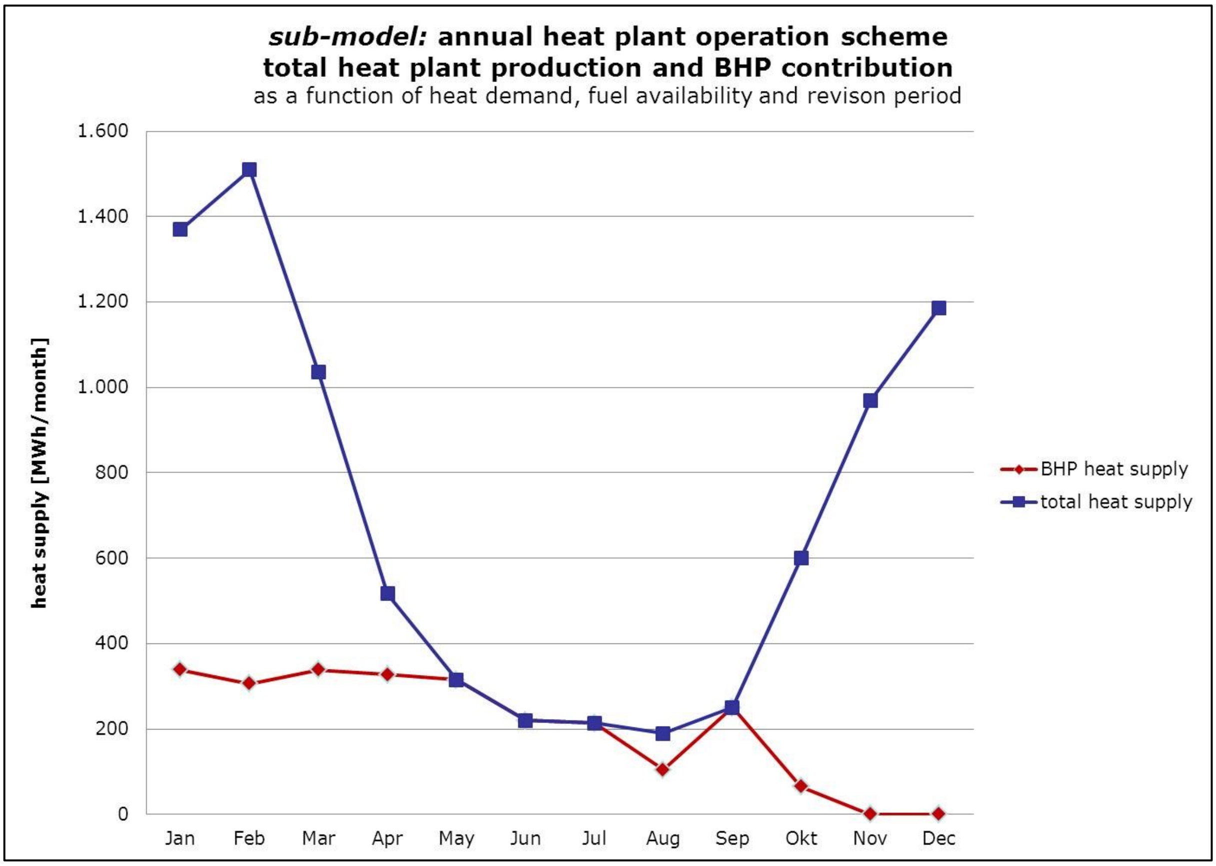

Fig. 5.8.: Annual operation scheme of the woodchip fired heating plant, example case: Scenario with insufficient fuel availability and short revision period in summer.
(Source: Authors' design, underlying calculations and graphical illustration by U. Arnold with the help of MS EXCEL 2010 and MS PowerPoint 2010).

The option of reactivating the idle CHP units was taken into account somewhat roughly without a separate sub-model for the annual CHP-operation since detailed characteristics and specifications of the CHP units were not available. Therefore, in simulation cases with assumed CHP-operation the annual total heat demand was simply reduced by the annual CHP contribution and the remaining heat demand was modulated like in (**Fig. 5.8.**) (blue line (in web version)).

5.4.4. Financial analysis results of the application case

Table 5.1. (**Tab. 5.1.**) summarizes the discriminating input features and analysis results of the incremental system optimization process.

sce-nario no.	description	BHP nom. boiler power	BHP invest. sum.	CHP-Oper.	available fuel volume	initial woodchip price	humidity	equity rate	i_D	NPV	ROE	$R_{NPV<0}$	F (NPV <=0)
		[kW_{th}]	[1,000 €]	[on / off]	[stere/yr]	[€/stere]	[%]	[%]	[%]	[€]	[%/a]	[€]	[%]
1	initial project configuration	500	800.00	off	2,500	25.00	30.00	32.00	6.00	-244,973	<0	n.a.	n.a.
2	initial p. config., reduced BHP-invest.	500	640.00	off	3,750	25.00	30.00	24.00-25.00	6.00	≈100,000	≈5.00	n.a.	n.a.
3	initial p. config., reduced woodchip price	500	640.00	off	2,500	20.00	30.00	24.00-25.00	6.00	≈100,000	≈5.00	n.a.	n.a.
4	unlimited fuel availability after year 3	500	800.00	off	5,000	25.00	30.00	20.00	6.00	171,122	6.06	32,543	21.00
5	unlimited fuel availability after year 3, CHP on	500	800.00	on	5,000	25.00	30.00	20.00	6.00	76,573	4.05	55,649.35	34.80
6	initial project but reduced capacity	250	400.00	on	2,500	25.00	30.00	19.05	6.00	50,670	4.07	42,368	39.30
7	like sc. 6 but increased fuel availability	250	400.00	on	3,000	25.00	30.00	19.05	6.00	52,571	4.74	33,076	32.40
8	like sc. 7 but reduced BHP price	250	360.00	on	3,000	25.00	30.00	19.05	6.00	99,622	5.87	16,796.74	19.00
9	like sc. 8 but reduced initial fuel price	250	360.00	on	3,000	22.50	30.00	19.05	6.00	169,659	7.95	4,727.11	6.60
10	like sc. 8 but risk hedged fuel supply	250	360.00	on	3,000	25.00	30.00	19.05	6.00	158,116	8.01	1,177.84	2.70
n	theoretical optimum financing & woodchip price	250	360.00	on	3,000	22.50	30.00	19.05	6.00	197,117	8.66	422.53	1.10

Tab. 5.1.: Application case: financial analysis and risk assessment results.

(Source: Authors' design, underlying calculations and graphical illustration by U. Arnold with the help of MS EXCEL 2010 and MS Word 2010).

Significant for the evaluation of profitability is the NPV at given discount interest rate and equity rate. In order have a measure for the average ROE the following simplified procedure was applied: With the assumptions of complete payment of equity EQ_0 in the beginning, of complete refraining from dividend payments, complete depreciation of the assets to zero and full amortization of loans and debts during the simulated project life-cycle, the final value of cash at bank C_n after n years is equal to the sum of initial equity payment and retained net earnings (cumulated net profit). ROE can easily be estimated with:

$$\overline{ROE} = [C_n/EQ_o]^{\frac{1}{n}} - 1 \tag{5.12.}$$

The ROE-measure of equation (5.12.) was preferred to the internal rate of return (IRR) for case comparisons since the EXCEL-provided function IRR turned out not to be as reliable as ROE due to sometimes occurring multiple solutions of the iteration algorithm.[23] The measures of aggregated risk, i.e. cumulated financial risk of negative NPVs $R_{NPV<0}$ [€] and the cumulated distribution function $F_{NPV\leq 0}$ [%], were derived from the MCS generated pdf of the NPV, using equations (5.2.) and (5.4.) resp. (5.8). Monte Carlo Simulations were carried out with 10,000 sample runs each which took an average of 13 minutes with Microsoft EXCEL 2010 on a Dell Latitude E6430 notebook.

The incremental optimization of system design and configuration was carried out in 10 steps:

[23] Multiple solutions when using the IRR-function of EXCEL can be caused by negative net cash flows during the lifetime of the project (excluding Period 0). This can be the case, when the project faces a year requiring significant capital expenditure, e.g. for the replacement of major technical equipment. Another scenario for years with negative net cash flows may be given in initial years of plant operation with not yet sufficient fuel amount availability, e.g. due to problems during the gradual enlargement process of the woodchip catchment area via closing additional supply contracts or via development of forest management structures for adjacent forests in the first years of plant operation.
By using the modified IRR (MIRR) function, the above mentioned shortcomings of the IRR function could be avoided likewise. In fact, the way ROE is defined (see equation (5.12.)) in our model corresponds to a specific version of MIRR with 0% financing and reinvestment rates. However, this approach was not taken into consideration by the authors for two reasons: First, the additional parameters required for MIRR (e.g. return on investment taking into account of the risk of the investment as well as a reinvestment rate given the risk associated with the future investments of the cash flows (see Kierulff 2008)) are hard to derive within the given stakeholder scenario of semi-professional actors. Second, the authors tried to minimize the number of internal iterative calculation processes for the sake of system stability and single-step transparency.

a) Step 1: The initial project design and system configuration was characterized by the following features: At first, a nominal thermal plant capacity of 500 kW with an approximate estimate of 800,000 € of related investment volume was considered to be appropriate. The regional forestry cooperation offered to supply 2,500 stere/yr of pine woodchips with a humidity of 30% to the plant at an initial price of 25 €/stere. Plans of reactivating the CHP units came up in later phases of the project. The financial analysis showed that these system settings are far from being economically and financially feasible due to significantly negative NPV expectations.

b) Steps 2 and 3: With the same system configuration as in case 1, but with 20% reduced plant investment conditions for reaching positive NPV and ROE values were searched by means of slight adaption of the fuel supply conditions. Both with increased fuel availability by 50% of the initial volume and with a 20% reduced initial woodchip price highly profitable NPV results were to be expected. These variations served the purpose of probing possible optimization directions.

c) Step 4: Again the initial capacity (500 kW) and price of the plant were selected and the offered initial woodchip price of 25 €/stere was accepted without change, but unlimited fuel availability was assumed (5,000 stere/yr). This "big capacity"-version of the system works with high profit (NPV > 0), the residual risk values, however, turned out to be somewhat discouraging. So far, the simulations were carried out without assuming partial coverage of the base load by the CHP units. After being informed by the operator that this option was seriously taken into account, all following cases were investigated with the condition of CHP operation.

d) Step 5: As in step 4, but now with CHP operation. The NPV in this step was less than half of the case 4 results and the risk is significantly increased. In addition, the forestry cooperative pointed out that a doubling of the woodchip production area and volume was far from realistic possibilities.

e) Step 6: The plant capacity was adapted to the available fuel volume (2,500 stere/yr) and reduced to 50% of its initial value (250 kW). The investment amount was reduced proportionally. Now nearly the same NPV as in case 5 could be reached, the risk measures however were even worse than in the previous step.

f) Step 7: Still the fuel volume (2,500 stere/yr) was insufficient for a reasonable utilization of the plant capacity during the whole annual operation. A forestry potential analysis indicated that additional forest parcels in the relative vicinity could be gradually developed during a period of three years. By enlarging the stakeholder group with the related private forest owners the expansion of available fuel volume by 20% in three years was assessed to be feasible. With these assumptions, the project risk could be slightly reduced.

g) Step 8: A detailed market analysis of available furnace/boiler units of the 250 kW-class indicated that a reduction of the plant price by at least 10% was to be expected if a tender were carried out. Based on this price assumption and all other conditions of case 7 the NPV value could be nearly doubled and the risk could be cut by nearly one half.

h) Step 9: It was shown that a further significant increase of NPV and profitability and risk reduction to marginal values would be possible by reducing the initial woodchip price to 90% of the offered value. This suggestion, however, was severely rejected by the fuel suppliers because of its non-compatibility with actual market prices.

i) Step 10: The same high project profitability (investment incentive for investors) with even smaller residual risk values than in case 9 could be reached on the fuel supplier side. This was accomplished by using the contractual means of partial risk transfer to the fuel suppliers. The specific contract components analyzed in step 10 were the annual adaption of the woodchip price based on the consumer price index by means of an index formula and a bring-or-pay condition for the target amount of 3,000 stere/yr of woodchips beginning in year 3. Of course, risks concerning the validity and enforceability of the contracts and of the solidity of the contract partners persist (Sellers 1988).

Figure 5.9. (**Fig. 5.9.**) illustrates the stepwise optimization process which provided both: a maximization of the NPV (blue graph (in web version)) and a minimization of the cumulated sum probability of negative NPVs (red graph, $F(\mathrm{NPV} \leq 0)$). A comparison with the theoretical optimum of financing (case 11 in **Fig. 5.9.**), i.e. with highest debtor rating and lowest nominal loan interest rate (1.7%/yr, loan-program 271 of the German Federal Development Loan Corporation, Kreditanstalt für Wiederaufbau

(KfW)) showed that the profitability and risk results of the system configuration as analyzed in step 10 could be considered to be sufficiently close-to-optimum.

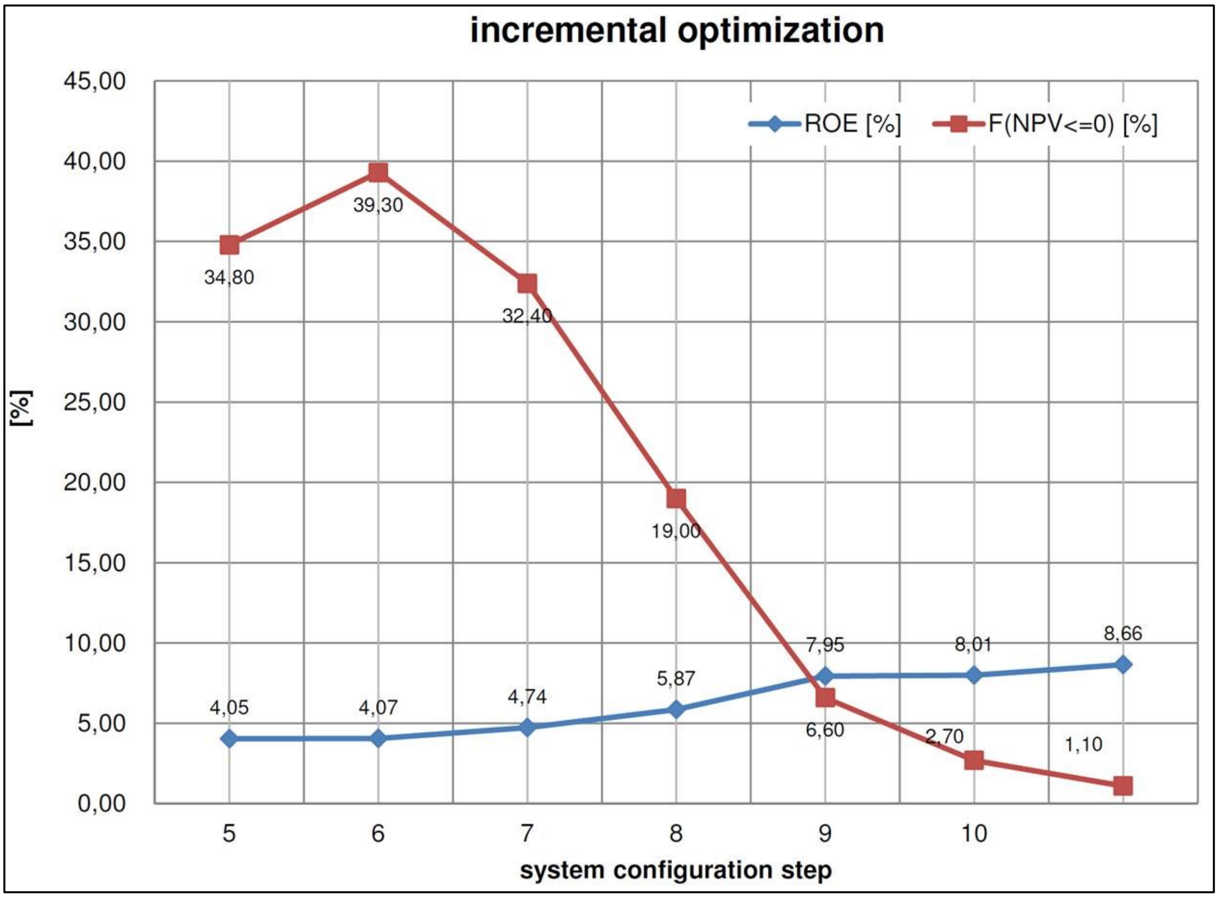

Fig. 5.9.: Incremental system optimization of the application case – comparison NPV and *R.* (Source: Authors' design, underlying calculations and graphical illustration by U. Arnold with the help of MS EXCEL 2010 and MS PowerPoint 2010).

Figure 5.10. (**Fig. 5.10.**) compares the initial (case 5 in **Fig. 5.9.**) and final state of the system behavior in terms of sensitivity and NPV-uncertainty. The progress and stabilization effects reached by the incremental procedure are evident in the slopes of the sensitivity curves and in the width of the pdf.

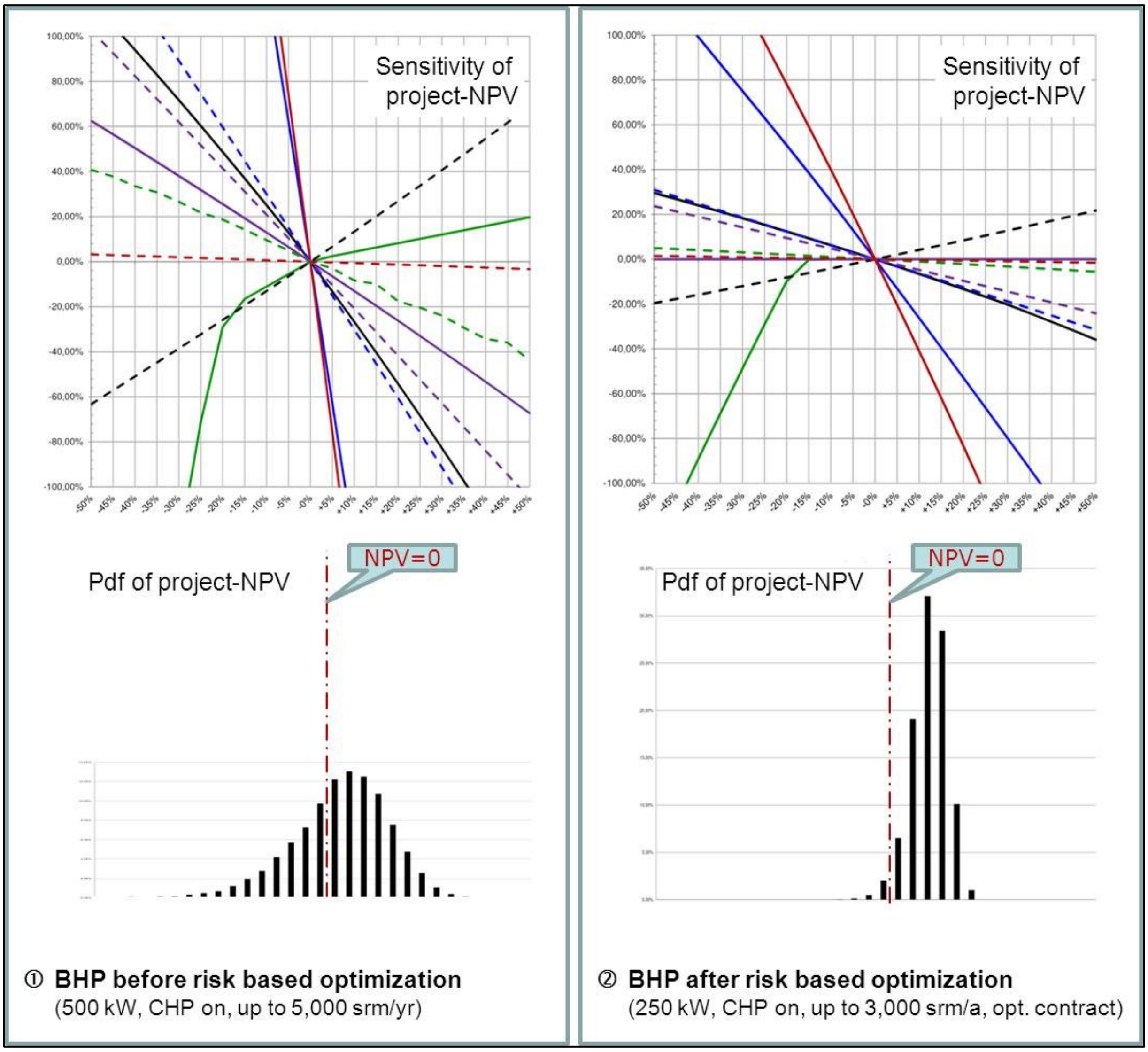

Fig. 5.10.: Incremental system optimization of the application case – comparison of sensitivity and NPV-uncertainty.
(Source: Authors' design, underlying calculations and graphical illustration by U. Arnold with the help of MS EXCEL 2010 and MS PowerPoint 2010).

5.5. Discussion and conclusion

With the financial analysis outputs of the application case example we were able to demonstrate that MCS generates substantial value-added information with respect to project risk that is relevant for investors, lenders and the feasibility of project financing. First, MCS offers considerable methodological advantages when compared with ordinary NPV-estimation or sensitivity analysis. It allows for varying several fuzzy or uncertain input parameters simultaneously within the financial assessment of a project which reflects the fact that forecasts are always exposed to some degree of uncertainty. Secondly, probabilities of being less or higher than a certain target value or of being within a confidence interval can be determined. Hereby, investors can assess the risk/return-ratio and volatility of an investment into an infrastructure project more easily. Finally, project participants can determine the effects of adjustments and stepwise variations in a project's design on project risk. It could be shown that the presented financial analysis combined with MCS aids in optimizing the conceptual design of an investment project with respect to capital returns and security. Since both issues are decisive for lenders and investors, the double-criteria analysis method presented in this paper could on the one hand facilitate the raising of capital for project investments, especially in the domain of small and medium scale RET infrastructures, on the other hand facilitate negotiations between project share- and stakeholders to undertake measures to divide remaining risks by displaying effects of adjustments within a project's design.

Still, the process of determining the probability density functions of the random MCS-input parameters is somewhat sophisticated and time-consuming as it requires information not only on expectation values but also on variation ranges, development trends and a specification of the distribution type. For frequently used quantities representing general boundary conditions and trends, such as prices, demography, and climate conditions etc., a repository of already determined input pdf-parameters and a matching tool for selecting the right ones for the case of interest would be extremely helpful. Moreover, satisfying the requirement of non-correlated MCS input parameters could be supported by embedded services of the repository. Future research and developments may lead to a generalization of the analysis method in such a way that even correlated random input parameters are permissible for risk assessment. For this purpose, the implementation of an advanced methodology instead of MCS will be necessary.

5.6. Literature

Alfen, H.W./ Riemann, A./ Leidel, K./ Fischer, K./ Daube, D./ Frank-Jungbecker, A./ Gleißner, W./ Wolfrum, M. (2010): *Lebenszyklusorientiertes Risikomanagement für PPP-Projekte im öffentlichen Hochbau*. Schriftenreihe der Professur Betriebswirtschaftslehre im Bauwesen der Universität Weimar Nr. 11, Bauhaus-Universität Weimar, Weimar, Germany, 2010.

Amigun, B./ Petrie, D./ Görgens, J. (2011): Economic risk assessment of advanced process technologies for bioethanol production in South Africa: Monte Carlo analysis. In: *Renewable Energy*, 36 (11), 3178-3186.

Böttcher, J./ Blattner, P. (2006): *Projektfinanzierung*. 1st edition, Oldenbourg Verlag, Munich, Germany, 2006.

Centrales Agrar-Rohstoff Marketing- und Energie-Netzwerk e.V. (C.A.R.M.E.N.) (2013): Preisentwicklung bei Waldhackschnitzeln - der Energieholz-Index.URL: http://www.carmen-ev.de/infothek/preisindizes/hackschnitzel/jahresmittelwerte (last time accessed 12.10.2015).

Cook, J.D. (2010): *Determining distribution parameters from quantiles*. UT MD Anderson Cancer Center Department of Biostatistics Working Paper Series – Working Paper 55, University of Texas, Houston, TX, 2010.

Del Río, P. (2007): Encouraging the implementation of small renewable electricity CDM projects: An economic analysis of different options. In: *Renewable and Sustainable Energy Reviews*, 11 (7), 1361-1387.

Del Río, P./ Burguillo, M. (2008). Assessing the impact of renewable energy deployment on local sustainability: Towards a theoretical framework. In: *Renewable and Sustainable Energy Reviews*, 12 (5), 1325-1344.

Gatti S. (2013): *Project finance in theory and practice: designing, structuring, and financing private and public projects*. 2nd edition, Elsevier/Academic Press, Amsterdam, Netherlands, 2013.

Gurgur, C.Z./ Jones, M. (2010): Capacity factor prediction and planning in the wind power generation industry. In: *Renewable Energy*, 35 (12), 2761-2766.

Hertz, D.B. (1964): Risk analysis in capital investment. In: *Harvard Business Review*, 42 (1), 95-106.

Jäger-Waldau, A./ Szabó, M./ Scarlat, N./ Monforti-Ferrario, F. (2011): Renewable electricity in Europe. In: *Renewable and Sustainable Energy Reviews*, 15 (8), 3703-3716.

Johnson, B.E. (1994): Modeling energy technology choices: which investment analysis tools are appropriate?. In: *Energy Policy*, 22 (10), 877-883.

Khan, M.A./ Khan, M.Z./ Zaman, K./ Irfan, D./ Khatab, H. (2014): Questing the three key growth determinants: Energy consumption, foreign direct investment and financial development in South Asia. In: *Renewable Energy*, 68, 203-215.

Kierulff, H. (2008): MIRR: A better measure. In: *Business Horizons*, 51 (4), 321-329.

Marmidis, G./ Lazarou, S./ Pyrgioti, E. (2008): Optimal placement of wind turbines in a wind park using Monte Carlo simulation. In: *Renewable Energy*, 33 (7), 1455-1460.

Masini, A./ Menichetti, E. (2012): The impact of behavioral factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. In: *Energy Policy*, 40, 28-38.

Mudakkar, S.R./ Zaman, K./ Khan, M.M./ Ahmad, M. (2013): Energy for economic growth, industrialization, environment and natural resources: living with just enough. In: *Renewable and Sustainable Energy Reviews*, 25, 580-595.

Mumtaz, R./ Zaman, K./ Sajjad, F./ Lodhi, M.S., Irfan, M./ Khan, I./ Naseem, I. (2015): Modeling the causal relationship between energy and growth factors: Journey towards sustainable development. In: *Renewable Energy*, 63, 353-365. [Note: This article has been cited due to the request of one of the reviewers. In the following, the original article by Mumtaz et al. (2015) has been retracted at the request of the Editor-in-Chief and the Publisher. For further information on the reasons see the URL: http://www.sciencedirect.com/science/article/pii/S0960148113005004]

RePro (2013): RePro – Ressourcen vom Land – Regionale Ressourcennutzung. URL: http://www.reproketten.de/ (last time accessed 12.10.2015).

Ringel, M. (2003): Liberalising European electricity markets: opportunities and risks for a sustainable power sector. In: *Renewable and Sustainable Energy Reviews*, 7 (6), 485-499.

Schuler, A./ Weber, C./ Fahl, U. (2000): Energy consumption for space heating of West-German households: empirical evidence, scenario projections and policy implications. In: *Energy Policy*, 28 (12), 877-894.

Sellers, W.O. (1988): Macro-project risk: an investment banking view. In: *Technology in Society*, 10 (2), 155-164.

Wüstenhagen, R./ Menichetti, E. (2012): Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. In: *Energy Policy*, 40, 1-10.

Yildiz, Ö. (2014): Financing renewable energy infrastructures via financial citizen participation – The case of Germany. In: *Renewable Energy*, 68, 677-685.

Zormaier, F./ Schardt, M. (2007): Waldhackschnitzel in Biomasseheizkraftwerken. In: *LWF aktuell*, 14 (61), 8-9.

Chapter 6: Nudging as a new "soft" tool in environmental policy – An analysis based on insights from cognitive and social psychology

by

Gabriela Michalek

Europa-Universität Viadrina Frankfurt (Oder)

Department of International Environmental Economics,

Prof. Dr. Georg Meran

Technische Universität Berlin

Department of Economic Policy and Environmental Economics,

Prof. Dr. Reimund Schwarze,

Europa-Universität Viadrina Frankfurt (Oder)

Department of International Environmental Economics,

and

Özgür Yildiz

Technische Universität Berlin

Department of Economic Policy and Environmental Economics

Discussion paper[24] published as:

Michalek, G./ Meran, G./ Schwarze, R./ Yildiz, Ö. (2015): Nudging as a new "soft" tool in environmental policy. An analysis based on insights from cognitive and social psychology. (No. 21). Discussion Paper Series recap15 – No. 21, European University Viadrina, Frankfurt (Oder).

URL: https://www.europa-uni.de/de/forschung/institut/recap15/downloads/recap15_DP021.pdf

[24] The style of the discussion paper was adapted in order to fit the formal style guidelines of this thesis. References within the text to other sections were also adapted in order to correspond with the denotation of this thesis. The appendix section of the original paper can be found at the end of this chapter.
By the time of the publication of this thesis, a revised version of this essay is submitted and under review at the scientific journal *Zeitschrift für Umweltpolitik & Umweltrecht (ZfU)*.

Abstract

The idea of nudging has become increasingly popular in both academic and political circles. There are, however, many different interpretations of the term ‘nudge’ which blurs its scope. In this paper we focus on the conceptualization of nudges and its functionality in reference to the Dual Process models. Further, we discuss the potential applications of nudging in the field of environmental policy as an important extension of the current policy framework. In particular, we identify areas where nudges could be most effective. We also consider different combinations of nudges with other policy instruments. Our theoretical discussion is illustrated by a couple of examples concerning practical implementation of nudging.

Keywords

nudging; green nudges; behavioral economics; household emissions; environmental policy.

Acknowledgments

The authors would like to thank Dr. Kathleen Cross for language-editing.

List of abbreviations in chapter 6

CAC	command and control
CF	carbon footprint
GHG	greenhouse gas
HER	Home Energy Report
UK	United Kingdom
US	United States (of America)

6.1. Introduction

Household emissions make up a considerable share of global greenhouse gas (GHG) emissions. This is especially true when the carbon emissions embedded in products and services are traced from their origin, through the world's supply chains up to the end consumers (households). Following this logic, the carbon footprint (CF) of an average (two-person) German household amounts to 30 tons of CO_2 equivalents per year. Indirect emissions spanning not only domestic but also foreign supply chains contribute in a major way to that figure (Miehe et al. 2015).[25] Thus, interventions that target emissions at the level of household consumption display considerable potential for mitigation, albeit potential that extends beyond administrative borders. As a consequence, they can also be used to address the growing problem of 'weak' carbon leakage.[26]

This mitigation potential, however, is very unlikely to be exhausted by the 'classical' production-based emissions control mechanisms such as cap-and-trade (Vandenbergh et al. 2008) or improved knowledge about climate change. This is because human behavior and, with it, individual consumption decisions are determined by several factors in addition to prices, product information or bans on goods and practices (behaviors) that are especially harmful for the environment. Specifically, factors such as structural barriers, the decision-making context, people's heuristics and cognitive biases have been proven to play an important role in the process of deciding what goods or services to purchase (Reisch and Hagen 2011).

These behavioral factors have recently attracted considerable attention, both from the research community as well as from policy makers, as offering a potential means of 'nudging' human behavior in a desirable direction. The governments of several countries including the US, the UK and, more recently, Germany have established special advisory divisions to design policy measures on the basis of insights from human behavioral research. The proponents of the nudging approach argue that this type of intervention may be particularly useful and effective in the 'pockets of behavior' where existing instruments have turned out to be virtually ineffective or politically

[25] Please note that in this context direct emissions are considered to be those caused by direct use of fossil fuels, e.g., by burning coal for heating or petroleum for private transportation, while indirect emissions are considered as those released during the production of goods and services consumed by private households.

[26] 'Weak' carbon leakage, defined as the net emission transfer between Annex B and non-Annex B countries, is a burning issue for climate policy, one which undermines its effectiveness and increases total mitigation costs. For a detailed discussion of this and other types of carbon leakage, see Michalek and Schwarze (2015).

unfeasible (Science and Technology Committee 2011). Other arguments in favor of nudges include the relatively low implementation costs and a high degree of compatibility with the values of modern individualistic societies (Moseley und Stoker 2013).[27]

In this paper we focus on a conceptualization of nudging and consider its potential for becoming a component of environmental policy. In particular, we investigate at what points and in what form nudging interventions could be deployed in order to achieve the best possible outcome on the basis of a positive economics approach. We begin our analysis in section 6.2. by introducing some basic concepts from cognitive and social psychology relating to Dual Process theories, which underlie the basic idea of nudging (Thaler and Sunstein 2008). This allows us to determine, in Section 6.3., the clear boundaries of the definitional and functional scope of nudges – an important task in view of the huge variety of interpretations of nudging in the literature. We also explain in this section how nudges can influence our intuitive and automatic decision-making process. The overview of the environmental policy toolkit, provided in Section 6.4., presents the options available to policy makers to control emissions and identifies nudges as an important complement to ‘soft' (non-restrictive) policy interventions and one which, up to now, had been absent from the toolkit. Section 6.5. discusses the effectiveness of nudges and related implementation issues. In particular, it identifies situations in which nudges may be most useful and effective. In section 6.6. we analyze the use of nudges in a policy instrument mix and investigate how nudging might improve the effectiveness of environmental regulation. Section 6.7. presents concrete examples of nudging options in Germany based on previous findings and on recent data regarding the CF of German households. Section 6.8. briefly summarizes our discussion, provides conclusions and highlights future research questions.

6.2. Human behavior from the perspective of cognitive and social psychology

Analyzing processes of human thinking and decision making is often based on the assumption that observed behavior arises from two distinct but interacting cognitive processes. The same framework also applies to the social context, where an individual is defined as a member of a group (see e.g., Evans 2003, Chen et al 1999).

[27] Please note that the nudging approach has also been heavily criticized, among other things, for manipulation, for impairment of choice and for compromising citizens' empowerment. For a normative discussion of nudges (see e.g., Goodwin 2012, Hagman et al. 2015).

The distinction goes back to research conducted in the 1970s and 1980s on attitudes and human behavior, which gave rise to the Dual Process theories. Although these models differ in their details, they are all based on the same underlying concept of two different cognitive processes and are thus mutually compatible and consistent (McElroy and Seta 2003). The first of these processes is automatic, intuitive and often emotion-driven, while the other is analytical, conscious and can be deliberately controlled (Petty and Cacioppo 1986: 'peripheral vs. central routes of processing', Epstein et al. 1992: 'rational vs. experiential systems', or Evans and Stanovich 2013: 'process 1 vs. process 2').[28] This paper adopts the terms cognitive process 1 and process 2, coined by Evans and Stanovich (2013), to refer to automatic and reflective cognitive processing respectively.

The cognitive operations entailed by process 1 can be described as fast and intuitive, and they often (but not always) lead to different types of cognitive biases that may result in suboptimal decisions. However, it should be stressed that intuitive actions can also be accurate and highly appropriate in certain decision–making situations (Simon and Chase 1973; Wilson and Schooler 1991; Klein 1998). For example, they have proven superior in decision-making contexts that demand fast decisions with minimal effort, such as those taken in traffic or while doing sports (see e.g., Gigerenzer and Brighton 2009). Further, process 1 is also responsible for frequently repeated and highly skilled actions which often require considerable experience (Kahneman 2003b). Process 1 was also proven to drive many social judgments when people's level of motivation is low (Chen et al. 1999). It is precisely such reactions that are difficult to influence by means of regulatory tools on account of their reflexive and habit-bound nature. In contrast, the deliberately controlled cognitive operations of process 2 are relatively flexible and thus adjust easily to any pre-defined rules. They are slower and more effortful than reactions governed by process 1 (Kahneman 2003b), although this does not mean that they are error-free. Extended use of process 2, for example, can lead to the so-called overthinking bias. This in turn can lead to so-called 'cognitive noise' and, as a consequence, reduce the consistency of the preferences (Amir and Lobel 2008, Lee et al. 1999).

It is important for our conceptualization of nudges to note that the boundaries between the two processes are fluid. Indeed they often interact in practice. Effortless

[28] For a brief discussion of the Dual Process models, see e.g., Lee et al. (2009) or McElroy and Seta (2003).

processes such as habitual behavior generally neither cause nor are affected by much interference when combined with other more effortful tasks. On the contrary, actions governed by process 2 tend to disrupt parallel cognitive processes, as the overall capacity for mental effort is limited. Nonetheless, deliberate reasoning is to some extent always involved in controlling both mental processes (Kahneman2003a). Thus, cognitive processes can be arranged in the following order with regard to the frequency of their occurrence. First, the output generated by process 1 is always (though often very loosely) controlled and accepted by process 2. Second, the latter process intervenes and modifies intuitive judgments based on the perceptions and frameworks generated by process 1. Third, the decision results from a 'pure' process 2 judgment because no intuitive cues are available. Least frequently, intuitive input is rejected by reflective process 2 (Kahneman 2002).

6.3. What is nudging and how does it work?

The term 'nudge' has been popularized by Richard Thaler and Cass Sunstein. They describe a nudge as *"any aspect of the choice architecture* [decision environment[29]] *that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid. Nudges are not mandates. Putting the fruit at eye level counts as a nudge. Banning junk food does not."* (Thaler and Sunstein 2008: 6).

The above definition mentions some important characteristics of a nudge; however, it lacks a crucial reference, namely, to the Dual Process theory of thinking, which underlies the fundamental idea of nudging and distinguishes it from other interventions. This omission has blurred the definition of nudge and nudging and has led to the emergence of different interpretations of the concept depending on the research question and/or area of application concerned (Ölander and Thøgersen 2014; Science and Technology Committee 2011).

In order to clarify this issue, we argue that behavioral interventions that are effected automatically and intuitively (process 1) and without restricting the choices available are at the heart of the nudging paradigm (Grüne-Yanoff and Hertwig 2015). However, in many cases process 1 output serves as a starting point for an informed decision

[29] In environmental psychology the key term 'environment' is typically used in a broader sense to encapsulate both physical and conceptual factors (Kaplan and Kaplan 2009).

and thus has only an indirect impact on the final decision; this is consistent with findings from cognitive psychology (see e.g. Kahneman 2002; Evans and Stanovich 2013). In consequence, a distinction has emerged in the literature between ‘pure’ type 1 nudges, which address process 1 outputs (e.g. reflexes) and type 2 nudges (e.g. ‘social’ nudges), which target reflective decision-making processes based on the underlying intuitive and automatic stimuli (Hansen and Jespersen 2013).

Some studies on nudging also refer to ‘fuzzy nudges’, a term which describes ‘hybrid’ instances. These can work either as a nudge (addressing process 1) or as a non-regulatory instrument such as ‘pure’ information provision (targeting process 2) (Selinger and Whyte 2011). The way a ‘fuzzy nudge’ works can be illustrated by the example of Ambient Orb, a device that indicates real-time energy use by means of colored light signals. The color red, for example, represents high energy usage and can be interpreted rationally as an instruction (or recommendation) to turn off some electric appliances. However, it may also evoke an unconscious response to reduce energy use as a result of intuitive negative associations with the color red [30] (Selinger and Whyte 2011, Maan et al. 2010).[31]

Apart from the Ambient Orb, the literature (including the book by Thaler and Sunstein) contains many other contentious examples. Some of these measures were designed to explicitly to target conscious decision making governed by process 2, but have nevertheless been classified as nudges. They include, inter alia, financial incentives, bans, educational campaigns, and attempts at persuasion or creating norms (for a discussion of *“mistaken nudges”*, see e.g. Selinger and Whyte 2011, Hausman and Welch 2010).

Some of these “outliers” have been explicitly addressed by Barton and Grüne-Yanoff (2015) who, in addition to identifying well-established heuristic-triggering nudges, have also specified two other distinct functional groups, namely, heuristic-blocking and informational nudges.

[30] This kind of behavioral intervention is particularly effective because many people have been exposed to color priming from their early childhood. Consequently, red is often unconsciously associated with negative features such as risk, danger or error (examples include the red traffic light, the school teacher’s red pen to correct mistakes, red warning signals etc.; see Selinger and Whyte 2011). When the Ambient Orb glows with an amber-colored light, indicating moderate levels of energy use, an observer’s attention will be heightened. Green, on the other hand, indicating low energy demand, is a symbol of a stable situation and has been proven to exert a calming effect. For further details concerning the influence of colors on cognitive processes, see Gerend and Sias (2009) as well as Elliot and Maier (2007).

[31] In our view, however, the Ambient Orb could also be interpreted as a ‘pure’ type 2 nudge, as the information it provides is particularly intuitive and accessible.

It is worth noting that the latter two categories of nudging are very distinct from the former one, although they all have a common aim: to ensure that an individual makes an 'optimal decision'. While heuristic-triggering nudges work within the environment of cognitive process 1 and thus bias or re-bias intuitive and automatic perceptions (so-called type 1 bias), the two remaining groups try to push an individual away from process 1 and towards the reflective thinking governed by process 2. These tools have also been referred to as self-deliberation and correction mechanisms, since they correct and/or eliminate cognitive biases often resulting from intuitive and automatic thinking (Amir and Lobel 2008). In other words, they de-bias our judgments. Such de-biasing can work well in the case of 'purely' automatic and/or intuitive judgments (addressed by type 1 nudges) in contrast to thoughtful decisions based on intuitive input (Amir and Lobel 2008; Kahneman 2002). Intuitive judgments can be relatively easily corrected by explicitly pointing out possible biasing factors and logical inconsistencies and thus stimulating reconsideration (Amir and Lobel 2008; see also Fischhoff 1981 for a detailed discussion of de-biasing techniques).[32] Increasing the time available for deliberation may also improve a person's ability to make the 'right' decision (Kahneman and Frederick 2002). In such a case the intervention seeks to correct the 'monitoring error' of reflective process 2 which gave the biased intuitive input the 'green light'. In consequence, the intuitive judgment can be adjusted accordingly (correction) or rejected in toto (elimination of bias) (Kahneman 2002; Amir and Lobel 2008).

It should be noted, however, that cognitive process 2 can also generate biases (the so-called type 2 bias), which are generally very difficult to correct (Amir and Lobel 2008).[33] What is meant here is the so-called 'overthinking' bias caused by extensive use of process 2. Nudging interventions can support the elimination of type 2 biases. In order for this to occur, an individual should be pushed towards an intuitive, heuristic-driven mode of thinking so that the 'rationale' for deploying nudges can be established.[34] Such a shift can be achieved, for example, by reducing the time available for deliberation and thereby impeding the person's ability to make a reflective decision

[32] Please note that 'de-biasing' - like nudging - has its limitations and may result in unexpected counter-effects. It is possible, for example, for someone to start paying particular attention to some factor that has been rendered salient by a regulator and in the process to begin to neglect another relevant factor. (Amir and Lobel 2008).

[33] At this point we do not refer to 'deliberate heuristics' because, due to the lack of information or time, a conscious use of such shortcuts is often the only possible solution. As a result, it cannot be classified as a decision-making error (Kahneman and Frederick 2002).

[34] Please recall that a nudge can bias or re-bias only when cognitive process 1 is involved.

(Amir and Lobel 2008). Figure 1 summarizes the above account and indicates how policy interventions can help people to make better decisions. This includes *unconscious* biasing and re-biasing by means of nudging (blue area) as well as *conscious* de-biasing by applying self-correction and self-deliberation techniques (red area), both interventions being aimed at reaching an 'optimal' decision (Amir and Lobel 2008; Selinger and Whyte 2011).

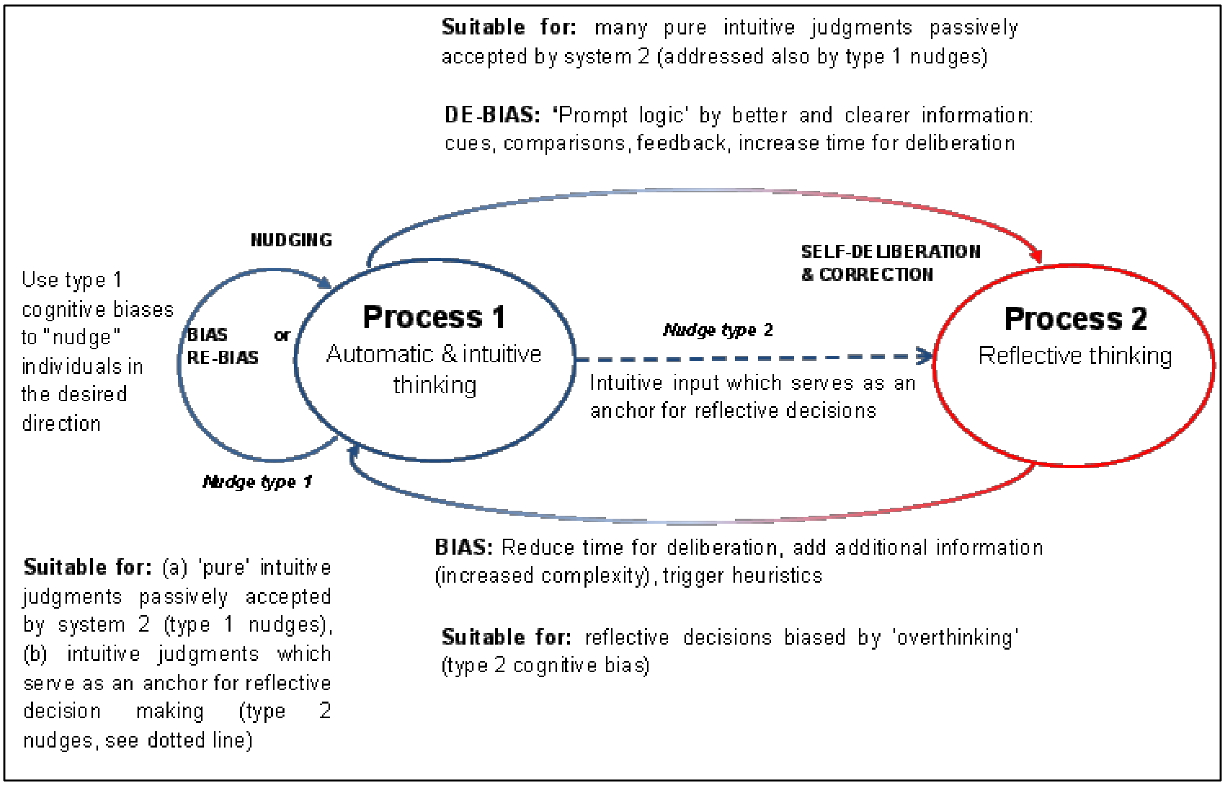

Fig. 6.1: A graphical representation of nudging, self-deliberation and correction process in relation to the interplay of cognitive process 1 and process 2.
(Source: Authors' design).

In this paper we follow the 'moderate' line of argument suggested by Hansen and Jespersen (2013) and assume that nudging interventions *always* aim at influencing cognitive process 1 and that this can evoke a behavioral change, both directly (type 1 nudge) and indirectly, through cognitive process 2 (type 2 nudge), (Hansen and Jespersen 2013, see Appendix to chapter 6 for specific examples of nudges).

But how does nudging work in practice? People often have to make decisions on the basis of incomplete information. Decisions based on complete information, if possible at all, are extremely rare and costly (in terms of time and cognitive effort). The resulting 'bounded rationality' can be the outcome of either deliberate or intuitive processing (dominated by process 2 or process 1 respectively) (Kahneman and Frederick 2002). The first case is usually determined by time and informational constraints which make an individual decide *consciously* to focus solely on a particular dimension or aspect. The second arises more naturally due to a limited attention span and cognitive capacity. Experiences, associations and heuristics stored in the associative memory which are easily accessible play an important role in this context since they enable a fast reaction. Due to the so-called 'attribute substitution' process heuristics are often used as a proxy for a related attribute to be assessed, which is not accessible in a given choice situation (Kahneman and Frederick 2002; Kahneman 2002). Some attributes, especially those encountered repeatedly in daily situations, are always at hand.[35] Others need to be made readily accessible, e.g. by exposure near in time to the decision or by a prior priming process (Kahneman and Frederick 2002). Such heuristic-driven behavior often leads to cognitive biases which, however, are generally fairly predictable (Kahneman and Frederick 2002).

Nudging is based on knowledge about such intuitive, heuristics-driven processes. It takes advantage of the fact that a particular choice architecture is always present. By adjusting this architecture appropriately, nudges can shift human attention to a particular aspect of the choice and thus trigger corresponding heuristics and associations. This affects the output of cognitive process 1 and makes an individual much more likely to make a choice in accordance with the regulator's expectations. Popular nudging techniques used to implement this knowledge in practice include framing, defaults (which can be considered as a special form of framing) and priming. While the first two methods influence the decision-making process through direct changes to the choice architecture, the second of these does so indirectly by referring to a previously primed piece of information or impression (Scheufele and Tewksbury 2007).

In particular, framing refers to the presentation of a given choice situation where particular attributes are made salient.[36] This evokes information and/or associations and

[35]Kahneman and Frederick present a short list of attributes – heuristics which are accessible by principle. These include e.g., size, distance or similarity, to name only a few (Kahneman and Frederick 2002).

[36] Depending on the type of feature emphasized (risk connected to choice, characteristic of an object or outcome of a behavior), the factor affected (preferences for risk, assessment, intention to engage in a particular behavior) and the resulting evaluation of the framing intervention, one can distinguish between 3 categories: risky choice, attribute and goal framing (Levin et al. 1998).

feelings connected with the emphasized attribute (Morewedge and Kahneman 2010). In consequence, the perception of a given choice situation as well as the preferences of the choice maker can become affected (Kahneman 2002).

In a similar vein, defaults can be considered as a special type of framing. Simple defaults denote a pre-defined (standard) option in addition to the other choice options.[37] The pre-selected option is determined in advance by the regulator and remains unchanged in most cases. The reasons for such 'stickiness' can vary greatly and include first and foremost (a) limited cognitive capacity to make a decision (e.g. due to thinking effort, time pressure etc.) as well as several cognitive biases.[38] These encompass (b) the perception of a default as an implicit recommendation evoked by uncertainty or a lack of expertise in a given field, fear concerning changes in the status quo resulting from (c) the endowment effect (Ölander and Thøgersen 2014; Sunstein and Reisch 2013) or (d) the so-called omission bias. In the latter case, an active negative behavior is considered to be worse than inaction with an equivalent final outcome (Beretti et al., 2013). Finally, some scientists have tried to explain the effectiveness of defaults by means of 'query theory', according to which the order of a person's thoughts influences their decision-making process (Johnson et al. 2007). Thus, the first thought or choice option can be understood as an anchor in relation to which other options are considered (Reisch and Hagen 2011).

Priming, in turn, influences cognitive process 1 only indirectly by means of a stimulus experienced prior to the choice situation in question, e.g. a stimulus of self-confidence before solving a complex mathematical problem. Such previous exposure increases the accessibility of particular thoughts, attributes and impressions and thus makes them more likely to appear in subsequent – sometimes thematically very different – situations (Hallahan 1999). The frequency and recent timing of exposure to a stimulus (which determine its accessibility in the memory) are of crucial importance to the effectiveness of priming (Brewer et al. 2003).

However, the notion of framing can also be extended beyond the conceptual level to the physical environment. In art sciences, for example, the term framing refers typically to the position of physical objects and pictures. In these cases framing influences the interpretative meaning and subjective understanding of the situation or observed object (Brown et al. 2015). Please note that physical positioning is also an example of a nudge.

[37] For a detailed discussion of different types of defaults, see Johnson et al. (2012).

[38] It should be noted that, like heuristics, defaults can also be effective in the framework of reflective thinking governed by process 2. This is the case when a person decides rationally to rely on the pre-defined option and thus saves cognitive effort and time which they can invest in other activities to maximize their own utility. The potentially broad application of defaults (in decisions governed by both process 1 and process 2) explains the high degree of effectiveness of this tool.

6.4. Nudges as an extension of the policy toolkit

Environmental policy which seeks to prompt behavioral change at the consumer level (e.g. consumption of low-carbon goods, use of renewable energy, sorting waste, or buying energy-saving appliances etc.) encompasses a wide range of different interventions. Here we focus on those that target individual consumers directly. However, most of them (including nudges) can also affect consumers indirectly by directly regulating the supply side; this is sometimes called 'budging' (Oliver 2013; Oliver 2015; Science and Technology Committee 2011).

Environmental interventions can be broadly divided into two categories: those that restrict choice and those that are non-restrictive. The former include primarily mandatory regulations and bans as well as command and control (CAC) measures, such as standards. They influence human behavior by restricting or eliminating particular choice options e.g. a smoking ban in public areas, an obligation to vaccinate etc. The overall improvement in social welfare that can be achieved by these behavioral commands constitutes the main legitimization behind this kind of policy to control externalities, and it is *normatively undisputed*. However, potential societal resistance towards the regulation, which may significantly undermine its effectiveness, constitutes a *non-negligible* problem within this group of instruments (Science and Technology Committee 2011).

The second category encompasses tools that guide individual behavior in a direction deemed beneficial by the regulator (e.g. environmental protection and/or sustainability), but *does not formally restrict* an individual's freedom of choice. As such, these tools can be called 'soft' policy instruments. This group includes in particular such established policy instruments as economic incentives (positive or negative monetary incentives), persuasion through information provision, moral suasion and educational campaigns.

These instruments clearly differ in their degree of 'softness'. The high costs of a particular option do not formally prohibit its being chosen, but they do often rule it out of the set of feasible choices due to budgetary constraints.[39] Information and appeal to moral arguments, on the other hand, have a much lesser impact on this set of feasible choices; they may be acknowledged or neglected regardless of the financial con-

[39] One can argue that this point is significantly weakened by the broad availability of financial instruments such as loans.

ditions. Despite these differences, all the instruments mentioned above have one important feature in common: they assume that people think about and compare the options available and finally make a utility-maximizing decision in accordance with their individual (stable) preferences. Thus, the underlying cognitive operation is ruled by reflective process 2. However, human behavior is much more often driven or strongly influenced by the automatic and intuitive responses generated by process 1 (cf. section 6.2.). These are, in turn, determined by various heuristics, mental shortcuts and cognitive biases arising from restricted cognitive capacity and attention span (Reisch and Hagen 2011). This particular type of decision-making process is addressed explicitly by nudges, which exploit the above-mentioned characteristics of intuitive thinking. Thus, nudges extend the spectrum of 'soft' policy instruments beyond interventions that address deliberate thinking into the sphere of intuitive and automatic decision making. This extension constitutes an important step forward towards more effective regulation that targets changes in human behavior. Table 6.1. (**Tab. 6.1.**) illustrates how nudges complement the existing policy toolkit from a regulator's perspective, taking into account the psychological foundations of human behavior.

Degree of softness

	Dominated by process 1		**Dominated by process 2**
Instruments that restrict choice*	Regulation that has become deeply rooted in the culture, beliefs, societal style of life	Bans Mandatory rules CAC measures ← →	Bans and mandatory rules with *low-level* punishment for non-compliance (incentive to consider whether obeying the regulation 'pays off', Tenbrunsel and Messick (1999))
Instruments that do not restrict choice ('soft' tools)	'Pure' Nudge (Type 1)	Nudge (Type 2)	Monetary incentives Non-monetary incentives Persuasion Moral suasion Pure information provision etc.

* In an extreme case, instruments that restrict choice can lead to a *physical elimination of choice*, e.g. command-and-control measures such as technical standards, which prohibit non-complying products from entering regulated area. If a particular option is not available in the choice architecture, the individual cannot process it mentally, and so this extreme case is not reflected in the table above. Please note that in the case of choice restricting instruments the undesirable options do not vanish from the choice architecture – they are simply beyond the scope of choice due to the regulatory stipulations. Disobeying the regulations may broaden the scope of choices but is done at the expense of incurring the consequences of non-compliance (punishment).

Tab 6.1: Regulatory vs. psychological perspective on policy instruments to control emissions at the household level.
(Source: Authors' design).

6.5. On the effectiveness of nudges

The practical application of any policy instrument is determined largely by its effectiveness. Other important factors include the costs associated with the intervention (will it be cost efficient?) and political feasibility (will the citizens of a given society accept it?). Since most nudges can be implemented at a *relatively* low cost and are less restrictive of choice than standard economic instruments such as price mechanisms (cf. degree of 'softness'), we need to focus primarily on effectiveness when discussing nudging in the policy making context. One important question to be answered is this: to what extent and in what situations can nudges be particularly effective?

Evaluating the effectiveness of a policy tool is not an easy task. A naive approach would be to infer a general statement about the performance of nudges based on a large number of relevant case studies. Following this logic, it could be said that nudges can induce behavioral changes in a number of different domains such as environmental policy and energy efficiency (see e.g., Pichert and Katsikopoulos 2008; Sunstein and Reisch 2013; Ölander and Thøgersen 2014), health (see e.g., Downs et al. 2009; Marteau et al. 2011; Dayan and Bar-Hillel 2011), organ donation (Johnson and Goldstein 2003; McKenzie et al. 2006), savings (see e.g., Madrian and Shea 2001; Willis 2013; Clark et al. 2014), insurance decisions (see e.g., Johnson et al. 1993), and car purchase decisions (see e.g., Park et al. 2000), to name a few examples.

However, it has to be acknowledged that methodological issues and the design of the study (such as characteristics of the study participants and the experimental setting or the type of nudge involved) can have a substantial influence on the final results. This makes it very difficult – if not impossible – to make any reliable statements about the general effectiveness of nudges. Consequently, different nudging tools implemented in specific environments (determined by the decision-making context, population etc.) can be expected to show different levels of effectiveness (Baldwin 2014; Bao and Ho 2015).[40] Finally, it should be noted that experimental tests do not always accurately predict how individuals would behave under real-world conditions (Alemanno and Spina 2014).

In light of these limitations, theoretical insights from cognitive and social psychology concerning human decision-making may prove to be very helpful. Based on the theoretical discussion in section 2 one can deduce that nudges, which are rooted in automatic and intuitive processes, should be *most effective* when applied to behavioral situations dominated by cognitive process 1 such as reflexes and to frequent (repeatable) actions characterized by a relatively low degree of personal relevance. Such 'low involvement' decisions[41] include many activities performed on a daily basis

[40] See different results on saving behavior in Madrian and Shea (2001) compared to Beshears et al. (2010) and Bronchetti et al. (2011).

[41] The term 'low involvement' is commonly used in marketing research to describe activities or products that induce low personal motivation to consume a specific product, search and/or interpret relevant information concerning this product (Gordon et al. 1998). In fact, some academics argue that the nudge approach is not new and that it has been used for many years in practice by marketing people. Thus, they argue, nudging as a policy tool is very similar to marketing efforts, with one substantial difference: the maximization of individual/social welfare instead of profit maximization which can result in substantial redistributive effects (Mont et al. 2014, Reisch and Hagen 2011, Amir and Lobel 2008).

such as choosing a lunch option, doing the grocery shopping, using a means of transport to go to work/school etc. Many of these decisions become ‘automatic’ habits over time. It is worth noting that this category can also include highly complex behaviors that have become extremely well learned and thus no longer require any (conscious) thinking (cf. section 6.2.).

This hypothesis has been supported empirically by analyzing people’s susceptibility to framing effects, an established nudging technique. As anticipated, the respondents working on a personal low-relevance task (the effect obtained by purposeful manipulation) were more likely to modify their judgment as a consequence of a corresponding framing than those who received personally relevant tasks. Similar though less homogenous results were obtained in a second experiment where natural predispositions towards ‘analytic’ vs. ‘holistic thinking’ were studied (see McElroy and Seta 2003 for a detailed description of both experiments and a brief overview of other studies with similar results). The enhanced performance of nudging interventions (in this case ‘social nudges’ relating to the social context) in low-involvement situations was also confirmed in a large field experiment. The results showed that people were much more likely to follow the descriptive normative beliefs (anticipation of another’s behavior – a form of ‘social nudge’) if they were not personally involved in the issue. The effect of descriptive normative beliefs on the behavior of highly-involved people was proven to be still positive but weaker (Göckeritz et al. 2010).[42]

This effect could not be observed, however, in the studies on framing effects in personally relevant situations (McElroy and Seta 2003). Thus, the results on the nudges’ impact on behavior under conditions of high involvement are not unambiguously conclusive. From the psychological perspective, this can be explained by several different reasons. First and foremost, the two cognitive processes are not entirely unconnected to one another – very often they are both involved in the decision-making process. In particular, intuitive input such as emotions or impressions can underlie and thus indirectly influence a reflective judgment (see e.g., Kahneman 2002). Second, individuals differ in their ‘need for cognition’, i.e., some people tend to engage in the decision-making process in a deliberate and reflective way more than others (Petty et al. 2009). Third, the same stimuli can be processed in different ways, depending on

[42] It should be noted that involvement can be defined and measured in many different ways, depending on the subject of the study. The common denominator of these definitions is high personal relevance and potential consequences for the individual taking the decision (Petty et al. 1983, Göckeritz et al. 2010).

which process dominates: deliberative or automatic. For example, a picture can influence a judgment by evoking particular associations or impressions (an intuitive process). Alternatively, it can be interpreted and evaluated by another person as a source of relevant information (see e.g., Petty and Wegener 1999). Last but not least, the effortful and deliberate decision-making process is determined not only by motivation (e.g., personal relevance) but also by one's own (perceived) ability to solve the problem. The latter factor can be broken down further into the person's capability (e.g., knowledge of the specific subject, necessary skills etc.) and mental capacity (reduced by other tasks that need to be done in parallel, by time constraints, and by distractions) to perform the task in question. Thus, constraints affecting a person's ability to make a judgment exert a negative impact on the reflective decision-making process and encourage intuitive and automatic processing (McElroy and Seta, 2003, Ronis et al. 1989).

Changes (in attitude) evoked by automatic and intuitive process 1 are generally temporary and context dependent (Petty and Cacioppo 1981). In fact, some 'pure' nudges (type 1) that are driven primarily by process 1 (such as visual illusions) can be very strong – indeed almost irresistible, especially upon initial exposure.[43] However, as times passes and people gain experience with particular types of nudges, there is a high risk of the effect wearing off. This is very likely to occur in the case of visual illusions like speed control markings on roads. Local drivers travelling along a dangerous route every day may start to ignore the markings, whereas non-local drivers (to whom the markings are new or unfamiliar) are likely to heed them (Amir and Lobel 2008). In addition, there is a risk that individuals aware of such 'unavoidable' (quasi coercive) nudging might feel manipulated. This, in turn, may evoke psychological reactance, leading perhaps to an intentional countervailing action that is undertaken in an attempt to preserve one's own 'perceived freedom of choice' in response to a restrictive regulation (see e.g., Brehm and Brehm 1981; Bovens 2009; Wortman and Brehm 1975).

The performance of 'pure' nudges in canteens (a 'technical' adjustment of the choice architecture involving the highly accessible and visible positioning of healthy food) has not so far been reported to deteriorate over time, although serious concerns have been raised when it comes to people's behavior after they leave the canteen.

[43]However, professionals familiar with visual illusions (such as photographers or painters) tend to be an exception to this rule - they can often recognize visual illusions immediately (Kahneman 2002).

This situation has barely been addressed at all by studies of nudges used to promote healthy food. However, Wisdom et al. (2010) have highlighted the plausible risk that, after having had a light (low calorie) and healthy meal, people may become hungry and/or more tempted to eat more after lunch, to buy snacks etc., and that this can undo the good done by eating a healthy meal. In addition to this, very slight nudging interventions involving only one category of food (sandwiches, but not beverages or starters) have been shown to be ineffective due to an increased consumption of soda (fizzy) drinks and high-calorie snacks (Wisdom et al. 2010). Similar problems may arise in other domains as well. For example, the policy goal of reducing GHG emissions may be easily undermined by spending the money saved through energy saving on other aspects of consumption (e.g., going on holiday by plane) - the so-called indirect re-bound effect (see Druckmann et al. 2011 for a study on rebound effects with respect to GHG emissions).

The cases discussed so far refer to situations in which a nudge is used continuously. One might expect that the effectiveness of a nudge would be eliminated (or would decline rapidly) after it has been removed from the choice architecture because the 'decision' to engage in a particular action has been automatic and/or intuitive (one cannot expect drivers to slow down at a particular spot if the visual illusion is not evoked). In a similar vein, a person is rather unlikely to look for a healthy food that used to be located at the canteen entrance if they always take 'whatever' option is placed near the entrance[44]. Behavioral persistence could be generated by deploying four different techniques: (1) habit formation, (2) influencing a person's way of thinking, (3) changes in future costs, and (4) creating behavior-reinforcing loops in the choice environment (for a detailed discussion, see Frey and Rogers 2014).

'Pure' type 1 nudges operating in the domain of cognitive process 1 are rather unlikely to fully exploit these 'persistence pathways' when used as a standalone tool. However, when combined with some deliberate thinking to initiate a new behavioral pattern (either a type 2 nudge or a type 1 nudge combined with a 'classical' non-restrictive instrument), nudges might become capable of developing persistence, provided that the intervention was repeated over a fairly long period of time. This can be illustrated by the example of Home Energy Reports (HER), sent out as a special

[44]This example assumes that the choice of a meal (e.g., during a short lunch break) is almost automatic. Of course, the situation might be different if the person has a lot of time to think about their choice and displays high involvement in relation to nutrition (e.g., I may choose my food very carefully because I am on a diet and am therefore determined to spend time and effort on finding suitable food).

service by the US energy efficiency company OPOWER, which are based on social comparisons and are thus a 'social' nudge. Initially, HERs were proven to prompt significant reductions in energy use a couple of days after being received; after that, however, the effect dropped off so fast that it would most likely disappear totally if the intervention was halted. However, after 2 years of regularly receiving the service, some indications of persistence were observed, albeit decreasing at a rate of 10-20 % each year. Such long-term effects could be explained primarily by a strengthening of habitual behavior (HER acts as a 'reminder' to repeat daily energy-saving actions) and by a growth in 'physical capital' (HER encourages people to invest in energy-saving equipment that produces energy savings in the long run[45]). The habit was not fully developed after two years, however, as households that continued to receive their HERs achieved much better energy-saving results than those which discontinued the service (Allcott and Rogers 2014).[46] Since habit formation was proven to follow an asymptotic curve in terms of effectiveness (Lally et al. 2010), it is important to continue with the intervention until the curve becomes flat and a habit is fully established.

The psychology literature provides some evidence that nudging can indeed facilitate habit formation – "habit" referring to an *automatic* behavior which is activated by a contextual cue and does not involve conscious thinking. Habits can evolve as a consequence of a repeated behavior performed in a stable context (Lally et al. 2010; Orbell and Verplanken 2010).

The two stages of each repeated behavior, *initiation* and *persistence*, are usually determined by different factors. Initiation requires that, in order to engage in a particular action to achieve a specific goal, a person attains awareness and engages in an 'active' mode of thinking. This process typically occurs in novel situations or when accustomed conditions change. In such a case the degree of thoughtfulness and thus the potential to establish or modify a behavioral pattern will depend on the personal relevance of the new situation. This can range from 'naturally' occurring changes, such as a change in appearance or changes in the choice environment (e.g., the un-

[45]Psychological studies show that even the first small positive changes in behavior (e.g., energy-saving behavior) can enhance a person's perception of their self-efficacy and thus encourage them to continue to behave accordingly; this can lead to involvement in further related activities (such as buying energy-saving appliance that amplify the initial effect, see e.g., Gardner et al. 2012).

[46]The time required to form a robust habit is still the subject of extensive research. Experiments indicate that it takes about 10 weeks on average to form a habit if an action is performed daily (Gardner et al. 2012).

expected absence of an option that is usually selected), to planned interventions, such as informational campaigns, attempts at persuasion, and so forth (to be discussed in greater detail in the following section on potential policy mixes). Persistence, on the other hand, is strengthened by resources and enabling factors such as skills, knowledge and, most importantly, memory (Ronis et al. 1989).

The so-called favorable environment – one which does not hinder but rather makes it easier to perform the desired action – also plays an important role. Actions that are easy to accomplish can be turned into automatic habits faster with the passing of time. Further, successful accomplishment reinforces the behavior in question and encourages further related outreach possibilities (Gardner et al. 2012). Since many people decide deliberatively to start a certain behavioral pattern but then falter when it comes to continuing it, persistence plays a crucial role in habit formation (Ronis et al. 1989).

Nudges encompassing a wide range of different measures could effortlessly adjust a given choice architecture to facilitate the enactment of certain behaviors in the habit formation stage. These might include physically re-arranging objects (positioning), providing memory-enhancing cues (implemented by the means of framing or priming), implicitly offering a recommendation in complicated knowledge-intensive decisions (defaults) and, finally, inducing specific thoughts and associations to trigger the automatic response when the habit has been already formed (Orbell and Verplanken 2010).

To sum up, we can conclude that there is a positive relationship between the involvement of cognitive process 1 in the decision-making process and the effectiveness of nudging. Nudging interventions can undoubtedly improve and simplify the human decision-making process by creating or re-shaping the cognitive biases generated by process 1 (so-called type 1 bias), which determines automatic responses or generates the cues that underlie reflective decisions (Amir and Lobel 2008). In particular, 'pure' (type 1) nudges can be recommended when a *fast, accurate*[47] *and situation-specific* response (no durable behavioral change) is desired. In such a case, however, policy makers must bear in mind the risk of psychological reactance. Nudges which encompass a degree of deliberate thinking (type 2), on the other hand, can prove highly suitable when regulators are seeking to achieve a lasting effect and have enough time and other resources to continue nudging over quite a long period

[47]It should be noted that 'pure' nudges such as reflexes or visual illusions are almost irresistible.

of time. In fact, a nudge that involves some deliberate thinking to engage in a particular behavior may help to develop a habit – a highly robust and durable form of behavior which may persist even once the underlying intention or motivation has disappeared (Ronis et al 1989; Gardner et al 2012). Particular attention should be paid, however, to the design of such interventions in order to avoid the formation of a bad habit – which is equally difficult to change as a good one. Last but not least, it should not be forgotten that nudging is also used to correct biases generated by cognitive process 2 (the so-called type 2 bias), which are generally very difficult to tackle (Amir and Lobel 2008, cf. section 6.3.).

6.6. Nudges in the Instrument Mix

The following section extends our conceptual and functional analysis by discussing the way nudges can be combined with other types of policy measures and the possible results of such instrument mixes.

The idea of implementing nudges 'in a package' to prompt behavioral change on a large scale has generally been supported by policy makers (Science and Technology Committee 2011). However, so far there are no coherent guidelines in existence for creating an effective mix of instruments containing nudges. This section aims to fill out this gap. First, we discuss the characteristics of an instrument mix and a more comprehensive policy mix. In a second step, we present some specific instrument mixes which contain elements of nudging.

The debate about "instrument and policy mixes" in the domain of environmental and sustainability policy and analyses of their respective effects have recently attracted considerable attention in the literature (e.g., Howlett and Rayner 2007; Flanagan et al. 2011). This has resulted in a diversity of definitional approaches, ranging from equating the term "policy mix" with the term "instrument mix" to more nuanced approaches. According to the former view, the term "instrument mix" refers to the combination of different instruments and their interaction (e.g., influences and modifications resulting from this interaction). In contrast to this, a more comprehensive definition of the term "policy mix" includes a process-oriented perspective, i.e., it also considers the processes by which policies emerge and the long-term strategic implications of a policy (Rogge and Reichardt 2013). In the following, the focus will be on the "instrument mix" perspective and on a discussion of the effects of their combined use.

Beginning with a discussion of the mixed use of nudges with bans, mandates and command and control mechanisms (collectively sometimes labelled as "shoves", see e.g., Sunstein 2014), these policy instruments are generally considered to be of a highly intrusive character. As such, they can hardly be regarded as a policy intervention derived from insights about the cognitive characteristics of decision making. In fact, regulators might be aware of various behavioral patterns that influence a person's decision making but may nonetheless consider the risk of the regulated subject not responding to a non-restrictive measure to be too high or not acceptable at all. Critics point out that bans and mandates can lead to over-regulation. Hence, if (empirical and/or experimental) evidence is gathered to show that a detrimental behavior can be avoided by nudges (at least for the majority of the population), then replacing restrictive mechanisms with nudges might avoid over-regulation from a strategic point of view (Di Porto and Rangone 2013).
Because of the restrictive nature of bans, mandates, and command and control mechanisms, a strategy that involves mixing them with nudges (i.e., mixed strategies) hardly seems feasible. Nonetheless, it might be possible to deploy such a combination in the form of mandatory cool-off periods (e.g., Guala and Mittone 2015; Mills 2015). The cool-off period can be described as a temporary limited ban aimed at reducing or eliminating fast and emotional responses often characterized by type 1 bias (Barton and Grüne-Yanoff 2015). With regard to our discussion above we would classify this intervention as a mix of self-deliberation (cf. section 6.3.) and regulation. However, it can be also regarded as a nudge enhanced by a ban when viewed from another point of view (cf. heuristic-blocking nudges described by Barton and Grüne-Yanoff 2015). In addition, it should be borne in mind that command and control policies implicitly include some elements of nudging because the "command" sets the normative default of socially desired behavior.
In addition to the human-centric perspective that usually underlies nudges, the rationale behind them – i.e., knowledge of cognitive processes, decision making and resulting behavioral patterns – can be the starting point for regulation informed by behavioral economics. This instrument (that is, combining the idea behind nudging with the tools of regulation and labelled in the literature as "budging") starts from a supply side perspective in order to counteract efforts at manipulation by the private sector on their own territory, instead of developing measures to counter harmful effects through behavioral changes on an individual, demand-side level. Behavioral

economics in this context, then, is not a rationale for choice-preserving nudges but rather provides a theoretical foundation for the limits of nudging (Oliver 2013). According to the idea of behaviorally informed regulation, budges can be divided into two types. In the first type, policy makers require knowledge of behavioral economics in order to detect private sector actions that are aimed at exploiting the behavioral patterns of individuals. A second type goes one step beyond this, consisting of regulatory measures that are informed directly by insights from behavioral economics in order to strengthen the effect of a budge. An example of the first type would be a ban on positioning unhealthy food at eye level in a supermarket in order to avoid companies using the influence of salience on individual behavior. An example for the second type would be to introduce a ranking system that addresses the characteristic of loss aversion and motivates companies to aim for a higher ranking (Oliver 2015).

Turning our focus to nudges combined with classical non-restricting policy tools, such as monetary incentives or the provision of information, we now offer a (brief) review of these tools in light of the insights about human decision making and cognitive processes presented above. Policy makers' expectations of these established tools are often shaped by the linear thinking of the neoclassical model, where individuals consciously process the information they are given[48] and respond "rationally" to it. Thus, policy makers considering the use of these established non-restrictive policy measures generally depart from this perspective when making projections on their expected effects (Selinger and Whyte 2011).

In contrast to these projections, the analysis of monetary incentives in particular suggests that a more differentiated perspective is needed. Here, a large amount of empirical and experimental evidence suggests that price instruments tend to be not as effective as expected (see e.g., Chetty et al. 2009; Gneezy et al. 2011; Bowles and Polania-Reyes 2012; Goldin and Lawson 2015). In this context, insights from cognitive processing and human decision making reveal that the informational effects of monetary incentives are accompanied by various behavioral patterns that operate through process 1 (i.e., intuitive and affective behavior). One significant example is salience: individuals know about monetary incentives when their attention is drawn to them but pay no attention to instruments that are not transparent to them when deciding what to buy (Chetty et al. 2009). Other affective patterns of monetary incen-

[48] Monetary incentives are a type of information but are also considered to have affective components, as we shall discuss below.

tives include the importance of reference points when judging the value or utility of a monetary incentive, loss aversion (which makes losses appear larger than gains), the greater significance accorded to small probabilities, and the allocation of money to 'discrete mental accounts' (Dolan et al. 2012). A third aspect is the interaction between social norms and monetary incentives. Here, the introduction of monetary incentives may crowd out intrinsic motivations and consequently diminish the incentives' effects (Gneezy et al. 2011).

Nudges place a greater emphasis on the duality of intuitive and deliberate thinking and work explicitly with the influence of intuitive thinking on human decision making (Selinger and Whyte 2011). In particular, they acknowledge that there is a heterogeneous population consisting of both active and passive choosers. Here, active choosers are representative of the deliberative decision process in that they consider the available information and make a choice according to their preferences. In contrast, passive choosers follow the pattern of intuitive behavior which (among other behavioral patterns) implies that they often simply pick whichever option is the default one (Goldin and Lawson 2015). Taking this heterogeneity into account, a mixed strategy of nudges and other non-restricting tools seems particularly appealing, as the mix would influence each group in turn, both the active and the passive choosers, through the appropriate channels (Griffith et al. 2014). However, there is still little knowledge about how these groups of policy interventions operate in practice, mainly due to the rather limited amount of empirical and experimental evidence available. Given the crowding-out effects of monetary incentives on voluntary contributions to public good provision due to social norms, an analogous situation might be conceivable here.

In this context, existing empirical findings so far have not revealed any negative interaction between nudges and pure information provision or feedback. In fact, health and nutrition studies have suggested that a combined use of both these tools may have a habit forming impact (Wisdom et al. 2010). Further research indicates that information and advice which explicitly address the techniques of how to engage cognitive process 1 can significantly increase the chances of producing long-term behavioral change (Gardner et al. 2012). Hence, habit formation might be one of the most promising aspects of an instrument mix that includes nudges and other non-restrictive policy instruments.

Additional implications for the design of an instrument mix emerge when efficiency is taken into account. Given a set of heterogeneous actors addressed by a certain policy intervention, the above mentioned rationale of active and passive choosers implies that there might be scenarios (e.g., a high proportion of passive choosers) in which command and control policies outperform monetary incentives. This evaluation of the efficiency of policy tools changes again when a particular type of nudges – namely defaults – are considered. As mentioned above, both defaults and command and control mechanisms set a standard for the addressees of a policy measure. In contrast to the restrictive command and control policy which solely foresees sanctions in the case of non-compliance, the default can be combined with explicit incentives so that deviations from the standard lead to additional costs *and* benefits. This mixed strategy offers active as well as passive choosers flexibility and "allows" them to make optimal choices according to their preferences. The result of this mixed strategy therefore outperforms one-dimensional policy measures, be they monetary incentives or command and control policies (Meran and Schwarze 2015).

Alongside the discussion of various instrument mixes that include nudges, it is also interesting to consider the parallel use of multiple nudging interventions ('a double nudge'). The empirical and experimental research in this area is still very limited. Empirical evidence from social psychology indicates that the effectiveness of descriptive norms (often used as a 'social' nudge) can be greatly enhanced by salience. In particular, it has been shown that in a littered environment (circumstances clearly implying a negative descriptive norm) people pay greater attention to the status quo when they see a person dropping waste and thus tend to litter more compared to a 'neutral' passer-by. In a similar vein, they litter less in a clean environment if their attention is caught by a person dropping waste and thus *evidently* violating the existing descriptive norm compared to the case of a person just passing by (Cialdini 2003). Further, empirical experiments indicate that using descriptive and injunctive norms in combination to point at desirable behaviors can be particularly effective. It has been hypothesized that this effect can be explained by the fact that these two types of social norms involve a different degree of cognitive processing and thus impact intentions and behavior in different ways. While descriptive norms are rather intuitive, injunctive norms typically require more cognitive effort, such as the interpretation and assessment of their content (Cialdini 2003) These considerations could be further extended to discuss the combined use of type 1 nudges (e.g. defaults) and type 2 nudges (e.g., an additional reference to social rules – a 'social nudge'). Since these two types of nudge would also require different levels of cognitive processing and use different impact channels (cf. section 6.3.), one might expect a mix of the two to improve their performance, particularly within a heterogeneous population (a hypothesis requiring empirical validation).

6.7. Possibilities for applying nudges – the example of Germany

The above theoretical discussion of nudges and of the situations in which they can potentially be applied has been based on insights from the Dual Process model and on considerations of efficiency and can be illustrated by reference to practical examples from the environmental domain. A recent study conducted by Miehe et al. (2015) identified those areas of consumption that contributed most to the average German household's carbon footprint in the year 2008 (GHG emissions were calculated using the MRIO model and were thus traced through global supply chains to German household final consumption). The results indicate that the largest amounts of (global) emissions induced by an average German household come from housing (34%), transportation (24%), food (18%), goods (15%) and services (9%). A considerable proportion of housing emissions come from direct use of fossil fuels, including oil and gas for heating and cooling, or electricity (indirect emissions). As regards transportation, most of the emissions comprised a direct use of fuel, followed by emissions from air transport. In the food category, most of the emissions were traced back to products of animal origin such as meat, eggs or cheese, largely due to the high amount of methane (CH_4) generated, which is a by-product of livestock farming. In the category 'consumption of goods' many embedded emissions could be accounted for as a result of recreation, culture and sports as well as clothing. Services entailed the lowest share of embedded emissions, which derived mainly from health care, education and other services (Miehe et al. 2015).

Empirical studies show that many nudges have been implemented successfully in areas of consumption such as housing, transportation and traffic, and food as a means of achieving various socio-political goals (see e.g., Rozin et al. 2011 as well as Marteau et al. 2011 for a study on how nudges can be applied to tackle the obesity problem, and Putnam 2015 for a system of "dancing traffic lights" that helped to increase pedestrian safety). It is interesting to note that these areas also turn out to be the most carbon-intensive. Within these broad categories, however, it is necessary to identify concrete mitigation actions where nudges could make a significant contribution towards climate protection.[49] The analysis presented above of the effectiveness of nudging in low- vs. high-involvement situations may be very helpful in this respect.

Home insulation can reduce direct energy use considerably; it is usually a decision taken just once, but one that requires significant investment. As a novel situation that places a burden on a household's budget, it can be considered a high-involvement decision which will not be taken without careful consideration and a comparison of options available on the market. A similar logic applies to private investments in renewable power generation, such as solar panels installed on the roof of a house. Here, monetary incentives, tax deductions, and educational campaigns that highlight the long-term savings can be expected to be most useful. However, as already mentioned, the benefits of taking particular actions may be stressed or made 'more intuitive' by the use of nudges. This will make the decision-making process easier and faster for those who would use logic in any case to arrive at the optimal solution ('active choosers') and will help those who may stumble during that process (e.g., due to information overload, limited attention), that is, the 'passive choosers' (Goldin and Lawson 2015).

Several studies have shown that applying defaults to electricity contracts increases the rate of use of renewable energy. Choosing an electricity provider is also a task undertaken rather infrequently; however, the cost difference connected with the choice of energy provider/ energy mix is rather small compared to the above mentioned investments. This activity can therefore be assumed to be lower in involvement than the previous two. It is very difficult to state clearly, however, the reasons why defaults show a high level of stickiness in this area and achieve results comparable to monetary incentives. A recent experiment conducted by Ebeling and Lotz (2015) revealed that almost 84% of respondents recalled well their choice of renewable energy as a default and thus took the decision consciously. This may indicate that, in many cases of choosing an electricity provider, people decide consciously to stick to the default, perhaps because of an implicit recommendation, their lack of expertise in the area, time constraints etc. It should be kept in mind, however, that defaults may be effective for any number of reasons and that these can vary between

[49]Grießhammer et al. (2010) identified ten activities to reduce GHG emissions most effectively at the household level using data from Germany. In the following we refer to some of these examples.

individuals (cf. section 6.3.). Regardless of the underlying reason, defaults display a high level of effectiveness in increasing the proportion of renewable energy used by household consumers; this suggests they should be applied increasingly in that particular domain. The question that policy makers should keep in mind concerns available renewable energy capacity: if from tomorrow all German households were to update their energy contract and a considerable proportion of them decided to keep the renewable energy mix set as a default, could this demand be satisfied (Ebeling and Lotz 2015)?

At the same time, nudges can prompt behavioral change much easier and faster than economic instruments when they are applied to many simple, repeatable activities performed daily, in other words in 'low-involvement' situations. The decisions taken on a daily basis are usually associated with rather low costs; they are of rather low or moderate personal relevance, and they often turn into 'automatic' habits. Although the potential GHG emissions reductions are rather low within each individual activity, when combined and aggregated over a longer period of time they make a significant difference. Such behavioral change could be achieved, for example, in the domain of transportation by improving public transportation to workplaces and schools (better coordinated network with a high-frequency service, increased number of stops which are visible and available within walking distance etc.) while also making appropriate infrastructural adjustments. This might include new bus and bicycle lanes as well as an altered 'street geometry' – the strategic arrangement of parking spaces that makes it impossible for drivers to reach their destination faster than pedestrians (Kordansky and Hermann 2011).

Considerable emissions reductions – often underestimated – could also be achieved in the category of food and nutrition. By placing seasonal, locally grown fruit and vegetables appropriately in shops (preferably those from organic farms that use no synthetic fertilizers, which are a source of nitrous oxides N_2O, a long-lived GHG, see United States Environmental Protection Agency), regulators can nudge consumers towards low-emission food that does not have to be transported by plane or ship or be stored for months in cooling warehouses. Even greater GHG emissions reductions in private consumption could be achieved by promoting vegetarian (non-meat) dishes in canteens and cafeterias, by improving the visual presentation of such meals, by making them more accessible (e.g., placing them near the entrance) or by applying knowledge about favorable ambient features (e.g., appropriate lighting, temperature, aroma etc. (Wansink 2004). A study of the carbon footprint of the most popular food products in Sweden conducted by Carlsson-Kanyama and Gonzalez (2009) showed that the consumption of 1 kg of beef results in the same amount of GHG emissions as the average emissions per passenger generated over a distance of 160 km using the European car fleet benchmark (Carlsson-Kanyama and Gonzalez 2009).[50] In addition, the use of 'green' nudges to reduce GHG emissions in low-involvement areas of everyday life could in many cases create desirable socio-political co-benefits, such as the health benefits of healthier food, a reduction in local pollution, not to mention individual budgetary savings.

6.8. Conclusion

By focusing on the use of nudges in environmental policy, we have obtained a number of insights concerning both the fundamental conceptualization of nudging and the practical implementation issues involved.

Nudges are often introduced to a broader audience through the work of Sunstein and Thaler (2008), who, by way of numerous case studies, describe how nudges might alter people's choice architecture and consequently influence their behavior. However, as we have shown, a closer look at the cognitive and social psychology literature is necessary in order to better understand the nature of nudges and their distinctive characteristics. With regard to our findings on Dual Process theories, one distinguishing characteristic of nudges is that they explicitly work with behavioral patterns resulting from intuitive and automatic cognitive processes. This accentuation of the importance of intuitive cognitive processes allows for a clear distinction between nudges and other 'soft' policy measures such as monetary incentives or educational campaigns, which are intended to target deliberate thinking. It also makes it possible to identify different types of nudges; 'pure' type 1 nudges and type 2 nudges, to use the nomenclature introduced by Hansen and Jespersen (2013).

Starting from these findings and the resulting categorization, nudges prove to be an important instrument within the environmental policy toolkit, as they are a key mechanism when it comes to addressing intuitive and habitual environmental behavior through policy instruments. Nudges can serve as a corrective measure in order to bias or re-bias human judgments in a desired direction without the use of active re-

[50] In the case of a tropical fruit an analogically calculated distance to produce the same amount of embedded emissions would be 60km.

flective reasoning. They therefore fill an important gap in the domain of non-restrictive, “soft” policy instruments targeting reflective cognitive processes.

When evaluating the effectiveness of nudges, a variety of aspects have to be taken into account. Cognitive psychology offers a rationale of how nudges work, but when it comes to practical implementation, it becomes clear that the ‘nudgee’s’ personal attributes and social circumstances as well as the broader perception of the nudge in society can result in a range of context-specific outcomes for the same tool, including potentially unexpected countervailing effects. Thus, policy design issues should be particularly well thought through.

With regard to a mixed strategy including other policy tools, nudges can be combined – as the group of type 2 nudges implies – with other non-restrictive policy measures. Here, a combination of nudges and other “soft” measures promises to address both kinds of cognitive processes and therefore to be particularly efficient given a heterogeneous population consisting of active and passive choosers (Goldin and Lawson 2015). A mixed strategy that includes restrictive measures (‘shoves’) seems to be difficult due to the intrusive character of the latter. However, ‘budges’ – behaviorally informed regulation – combine the rationale underlying nudges with restrictive measures and provide a tool for supply side interventions.

Although the amount of research on nudging is growing continuously, a number of research questions still remain unanswered. The theoretical rationale for nudging along with numerous case studies provide evidence for the effectiveness of nudges in many different domains, but there are also a few empirical examples of nudges having failed (see e.g., Beshears et al. 2010; Willis 2013). Some of these unsuccessful attempts at nudging might also have negative consequences for individuals. Given a heterogeneous population, particularly simple defaults or ‘social nudges’ can potentially damage the welfare of some individuals (Madrian 2014). Hence, further research is urgently needed regarding the effectiveness of nudges in the face of heterogeneous ‘nudgees’ and the possible negative spillovers. Furthermore, the combined use of classical policy tools with nudges is an area that requires further empirical verification. In the context of the long-term effects of nudges and their use in a mixed strategy, additional empirical and/or experimental research could be very useful when it comes to designing policies that reinforce certain beneficial habits. Finally, the combined use of different types of nudges (‘double nudges’) also largely remains an area in need of further research, especially in terms of practical implementation.

6.9. Literature

Alemanno, A./ Spina, A. (2014): Nudging legally: On the checks and balances of behavioral regulation. In: *International Journal of Constitutional Law*, 12 (2), 429-456.

Allcott, H. (2011): Social norms and energy conservation. In: *Journal of Public Economics*, 95 (9), 1082-1095.

Allcott, H./ Rogers, T. (2014): The Short-Run and Long-Run Effects of Behavioral Interventions: Experimental Evidence from Energy Conservation. In: *The American Economic Review*, 104 (10), 3003-3037.

Amir, O./ Lobel, O. (2008): Stumble, predict, nudge: how behavioral economics informs law and policy. In: *Columbia Law Review*, 108 (8), 2098-2138.

Araña, J.E./ León, C.J. (2013): Can defaults save the climate? Evidence from a field experiment on carbon offsetting programs. In: *Environmental and Resource Economics*, 54 (4), 613-626.

Ayres, I./ Raseman, S./ Shih, A. (2013): Evidence from two large field experiments that peer comparison feedback can reduce residential energy usage. In: *Journal of Law, Economics, and Organization*, 29 (5), 992-1022.

Baldwin, R. (2014): From Regulation to Behavior Change: Giving Nudge the Third Degree. In: *The Modern Law Review*, 77 (6), 831-857.

Bao, J./ Ho, B. (2015): Heterogeneous Effects of Informational Nudges on Pro-social Behavior. In: *The BE Journal of Economic Analysis and Policy*, 15 (4), 1619-1655.

Barton, A./ Grüne-Yanoff, T. (2015): From Libertarian Paternalism to Nudging and Beyond. In: *Review of Philosophy and Psychology*, 6 (3), 341-359.

Beretti, A./ Figuières, C./ Grolleau, G. (2013): Behavioral innovations: The missing capital in sustainable development?. In: *Ecological Economics*, 89, 187-195.

Beshears, J./ Choi, J./ Laibson, D./ Madrian, B. (2010): *The limitations of defaults*. NBER Retirement Research Center Paper No. NB 10-02, National Bureau of Economic Research, Washington, D.C. URL: http://www.nber.org/aging/rrc/papers/orrc10-02.pdf (last time accessed: 01.10.2015).

Bovens, L. (2009): *The Ethics of Nudge*. In: Grüne-Yanoff, T./ Hansson, S.O. [eds]: Preference Change: Approaches from Philosophy, Economics and Psychology. Springer Sciences, Dordrecht, Netherlands, pp. 207-220.

Bowles, S./ Polania-Reyes, S. (2012): Economic incentives and social preferences: substitutes or complements?. In: *Journal of Economic Literature*, 50 (2), 368-425.

Brehm, S.S./ Brehm, J.W. (1981): *Psychological reactance – A theory of freedom and control*. Academic Press, New York, NY, 1981.

Brewer, P.R./ Graf, J./ Willnat, L. (2003): Priming or Framing. Media Influence on Attitudes toward Foreign Countries. In: *Gazette: the International Journal for Communication Studies*, 65 (6), 493-508.

Bronchetti, E.T./ Dee, T.S./ Huffman, D.B./ Magenheim, E. (2011): *When a Nudge Isn't Enough: Defaults and Saving Among Low-Income Tax Filers*. NBER Working Paper No. 16887, National Bureau of Economic Research, Washington, D.C. URL: http://www.nber.org/papers/w16887.pdf (last time accessed: 01.10.2015).

Brown, Z./ Johnstone, N./ Haščič, I./ Vong, L./ Barascud, F. (2013): Testing the effect of defaults on the thermostat settings of OECD employees. In: *Energy Economics*, 39, 128-134.

Brown, E.B./ Gordon, Z./ Quinn, K./ Staking, K./ Stewart, N./ Zabriskie, C.H./ Visual Literacy Working Group (2015): *The Visual Literacy Toolbox (website)*. College of Arts and Humanities, University of Maryland. URL: http://www.humanities.umd.edu/vislit/modules_frameGaze.php (last time accessed 01.10.2015).

Carlsson-Kanyama, A./ Gonzalez, A.D. (2009): Potential contributions of food consumption patterns to climate change. In: *American Journal of Clinical Nutrition*, 89 (5), 1704S–1709S.

Carroll, G.D./ Choi, J.J.,/ Laibson, D./ Madrian B.C./ Metrick, A.(2009): Optimal defaults and active decisions. In: *The Quarterly Journal of Economics*, 124 (4), 1639-1674.

Chen, S./ Duckworth, K./ Chaiken, C. (1999): Motivated heuristics and systematic processing. In: *Psychological Inquiry*, 10 (1), 44-49.

Chetty, R./ Looney, A./ Kroft, K. (2007): Salience and taxation: Theory and evidence. In: *The American Economic Review*, 99 (4), 1145-77.

Cialdini, R.B. (2003): Crafting Normative Messages to Protect the Environment. In: *Current Directions in Psychological Science*, 12 (4), 105-109.

Clark, R.L./ Maki, J.A./ Morrill, M.S. (2014): Can Simple Informational Nudges Increase Employee Participation in a 401 (k) Plan? In: *Southern Economic Journal*, 80 (3), 677-701.

Costa, D.L./ Kahn, M.E. (2013): Energy conservation 'nudges' and environmentalist ideology: evidence from a randomized residential electricity field experiment. In: *Journal of the European Economic Association*, 11 (3), 680-702.

Dayan, E./ Bar-Hillel, M. (2011): Nudge to nobesity II: Menu positions influence food orders. In: *Judgment and Decision Making*, 6 (4), 333-342.

Di Porto, F./ Rangone, N. (2013): *Cognitive-Based Regulation: New Challenges for Regulators?*. Società editoriale federalismi s.r.l. Rome, Italy, 2013. URL: http://papers.ssrn.com/sol3/Papers.cfm?abstract_id=2382470 (last time accessed 01.10.2015).

Dolan, P./ Hallsworth, M./ Halpern, D./ King, D./ Metcalfe, R./ Vlaev, I. (2012): Influencing behavior: The mindspace way. In: *Journal of Economic Psychology*, 33 (1), 264-277.

Downs, J.S./ Loewenstein, G./ Wisdom, J. (2009): Strategies for promoting healthier food choices. In: *The American Economic Review*, 99 (2), 159-164.

Druckman, A./ Chitnis, M./ Sorrell, S./ Jackson, T. (2011): Missing carbon reductions? Exploring rebound and backfire effects in UK households. In: *Energy Policy*, 39 (6), 3572-3581.

Ebeling, F./ Lotz, S. (2015): Domestic uptake of green energy promoted by opt-out tariffs. In: *Nature Climate Change*, 5, 868-871.

Egebark, J./ Ekström, M. (2013): *Can Indifference Make the World Greener?* IFN Working Paper No. 975, Research Institute of Industrial Economics, Stockholm, Sweden, 2013. URL: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2324922 (accessed 01.10.2015).

Elliot, A.J./ Maier, M.A. (2007): Color and Psychological Functioning. In: *Current Directions in Psychological Science*, 16 (5), 250-254.

Epstein, S./ Lipson, A./ Holstein, C./ Huh, E. (1992): Irrational reactions to negative outcomes: Evidence for two conceptual systems. In: *Journal of Personality and Social Psychology*, 62 (2), 328-339.

Evans, J.S.B.T. (2003): In two minds: dual-process accounts of reasoning. In: *Trends in Cognitive Sciences*, 7 (10), 454-459.

Evans, J.S.B.T./ Stanovich, K.E. (2013): Dual-process theories of higher cognition advancing the debate. In: *Perspectives on Psychological Science*, 8 (3), 223-241.

Fischoff, B. (1981): *Debiasing*. In: Kahneman, D./ Slovic, P./ Tversky, A. [eds.]: Judgmenet under uncertainity. Heuristics and Biases. Cambridge University Press, New York, NY, 1981, pp. 422-444.

Flanagan, K./ Uyarra, E./ Laranja, M. (2011): Reconceptualising the 'policy mix' for innovation. In: *Research Policy*, 40 (5), 702-713.

Frey, E./ Rogers, T. (2014): Persistence: How Treatment Effects Persist After Interventions Stop. In: *Policy Insights from the Behavioral and Brain Sciences*, 1 (1), 172-179.

Gardner, B./ Lally, P./ Wardle, J. (2012): Making health habitual: the psychology of ‘habit-formation’ and general practice. In: *British Journal of General Practice*, 62 (605), 664-666.

Gerend, M.A./ Sias, T. (2009): Message framing and color priming: How subtle threat cues affect persuasion. In: *Journal of Experimental Social Psychology*, 45 (4), 999–1002.

Gigerenzer, G./ Brighton, H. (2009): Homo heuristicus: Why biased minds make better inferences. In: *Topics in Cognitive Science*, 1 (1), 107-143.

Gneezy, U./ Meier, S./ Rey-Biel, P. (2011): When and why incentives (don't) work to modify behavior. In: *Journal of Economic Perspectives*, 25 (4), 191-209.

Goldin, J./ Lawson, N. (2015): *Nudges, Mandates, and Taxes: Policy Design with Active and Passive Decision-Makers*. Available at SSRN. URL: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2585038 (last time accessed 01.10.2015).

Goldstein, N.J./ Cialdini, R.B./ Griskevicius, V. (2008): A room with a viewpoint: Using social norms to motivate environmental conservation in hotels. In: *Journal of Consumer Research*, 35 (3), 472-482.

Goodwin, T. (2012): Why We Should Reject ‘Nudge’. In: *Politics*, 32 (2), 85-92.

Göckeritz, S./ Schultz, P.W./ Rendo, T./ Cialdini, R./ Goldstein, N.J./ Griskevicius, V. (2010): Descriptive normative beliefs and conservation behavior: The moderating roles of personal involvement and injunctive normative beliefs. In: *European Journal of Social Psychology*, 40 (3), 514-523.

Gordon, M.E./ McKeage, K./ Fox, M.A. (1998): Relationship Marketing Effectiveness: The Role of Involvement. In: *Psychology and Marketing*, 15 (5), 443-459.

Grießhammer, R./ Brommer. E./ Gattermann, M./ Grether, S./ Krüger, M./ Teufel, J./ Zimmer, J. (2010): *CO_2-Einsparpotenziale für Verbraucher*. Öko-Institut e.V., Freiburg, Germany, 2010. Study also available on the internet, URL: http://www.oeko.de/oekodoc/1029/2010-081-de.pdf (last time accessed 03.07.015)

Griffith, R./ Smith, S./ Scholder, S.V.H.K. (2014): *Getting a healthy start? Nudge versus economic incentives*. Centre for Market and Public Organisation Working Paper No. 14/328(No. 13/328), University of Bristol, Bristol, UK. URL: http://www.bristol.ac.uk/media-library/sites/cmpo/migrated/documents/wp328.pdf (last time accessed 01.10.2015).

Grüne-Yanoff, T./ Hertwig, R. (2015): Nudge Versus Boost: How Coherent are Policy and Theory?. In: *Minds & Machines*. Published as online first article: DOI 10.1007/s11023-015-9367-9.

Guala, F./ Mittone, L. (2015): A political justification of nudging. In: *Review of Philosophy and Psychology*, 6 (3), 385-395.

Hagen, K. (2010): Nährwertkennzeichnung: Die Ampel erreicht die Verbraucher am besten. In: *Wochenbericht des DIW Berlin*, 77 (22), 2-12.

Hagman W./ Andersson, D./ Västfjäll, D./ Tinghög, G. (2015): Public Views on Policies Involving Nudges. In: *Review of Philosophy and Psychology*, 6 (3), 439-453.

Hallahan, K. (1999): Seven Models of Framing: Implications for Public Relations. In: *Journal of Public Relations*, 11 (3), 205-242.

Hansen, P.G./ Jespersen, A.M. (2013): Nudge and the Manipulation of Choice: A Framework for the Responsible Use of the Nudge Approach to Behavior Change in Public Policy. In: *European Journal of Risk Regulation*, 4 (1), 3-28.

Hausman, D.M./ Welch, B. (2010): Debate: To Nudge or Not to Nudge. In: *Journal of Political Philosophy*, 18 (1), 123-136.

Hirsch, L.E. (2007): Weaponizing Classical Music: Crime Prevention and Symbolic Power in the Age of Repetition. In: *Journal of Popular Music Studies*, 19 (4), 342-358.

Hossain T./ List, J.A. (2012): The Behavioralist Visits the Factory: Increasing Productivity Using Simple Framing Manipulations. In: *Management Science*, 58 (12), 2151-2167.

Howlett, M./ Rayner, J. (2007): Design Principles for Policy Mixes: Cohesion and Coherence in 'New Governance Arrangements'. In: *Policy and Society*, 26 (4), 1-18.

Johnson E.J./ Goldstein, D. (2003): Do defaults save lives?. In: *Science*, 302, 1338-1339.

Johnson, E.J./ Hershey, J./ Meszaros, J./ Kunreuther, H. (1993): *Framing, probability distortions, and insurance decisions*. In: Camerer, C./ Kunreuther, H. [eds.]: Making Decisions About Liability And Insurance. Springer Science, Dordrecht, Netherlands, 1993, pp. 35-51.

Johnson, E.J./ Keinan, A./ Häubl, G. (2007): Aspects of Endowment: A Query Theory of Value Construction. In: *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33 (3), 461-474.

Johnson, E.J./ Shu, S.B./ Dellaert, B.G.C./ Fox, C./ Goldstein, D.G./ Häubl, G./ Larrick, R.P./ Payne, J.W./ Peters, E./ Schkade, D./ Wansink, B./ Weber, E.U. (2012): *Beyond nudges: Tools of a choice architecture*. In: *Marketing Letters*, 23 (2), 487-504.

Kahneman, D. (2002): *Nobel Lecture: Maps of bounded rationality: a perspective on intuitive judgment and choice*. In: Frängsmyr, T. [ed.]: Les Prix Nobel – The Nobel Prizes. Nobel Foundation, Stockholm, Sweden, 2002, pp. 449-489. URL: http://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2002/kahnemann-lecture.pdf [last time accessed 03.04.2015].

Kahneman, D. (2003a): A perspective on judgment and choice. In: *American Psychologist*, 58 (9), 697-720.

Kahneman, D. (2003b): Maps of Bounded Rationality: Psychology for Behavioral Economics. In: *The American Economic Review*, 93 (5), 1449-1475.

Kahneman, D./ Frederick, S. (2002): *Representativeness revisited: Attribute substitution in intuitive judgment*. In: Gilovich, T./ Griffin, D./ Kahneman, D. [eds.]: Heuristics and Biases. Cambridge University Press, New York, NY, 2002, pp. 49-81.

Kaplan, S./ Kaplan, R. (2009): Creating a larger role for environmental psychology: The Reasonable Person Model as an integrative framework. In: *Journal of Environmental Psychology*, 29 (3), 329-339.

Klein, G. (1998): *Sources of power: How people make decisions*. MIT Press, Cambridge, MA, 1998.

Kordansky, M./ Hermann, G. (2011): Europe's parking U-turn: from accommodation to regulation. Institute for Transportation and Development Policy. ITDP – Institute for Transportation & Development Policy, New York, NY, 2011. URL: http://dcba.ie/wp-content/uploads/temp/2012/04/European_Parking_U-Turn.pdf (last time accessed 01.10.2015).

Lally, P./ Van Jaarsveld, C.H.M./ Potts, H.W.W./ Wardle, J. (2010): How are habits formed: Modelling habit formation in the real world. In: *European Journal of Social Psychology*, 40 (6), 998-1009.

Lee, L./ Amir, O./ Ariely, D. (2009): In Search of Homo Economicus: Cognitive Noise and the Role of Emotion in Preference Consistency. In: *Journal of Consumer Research*, 36 (2), 173-187.

Levin I.P./ Gaeth, G.J. (1988): Framing of attribute information before and after consuming the product. In: *Journal of Consumer Research*, 15 (3), 374-378.

Levin, I.P./ Schneider, S.L./ Gaeth G.J. (1998): All Frames Are Not Created Equal: A Typology and Critical Analysis of Framing Effects. In: *Organizational Behavior and Human Decision Process*, 76 (2), 149–188.

Liebig, G./ Rommel, J. (2014): Active and Forced Choice for Overcoming Status Quo Bias: A Field Experiment on the Adoption of "No junk mail" Stickers in Berlin, Germany. In: *Journal of Consumer Policy*, 37 (3), 423-435.

Maan, S./ Merkus, B./ Ham, J./ Middel C. (2010): Making it not too obvious: the effect of ambient light feedback on space heating energy consumption. In: *Energy Efficiency*, 4 (2), 175–183.

Madrian, B.C. (2014): *Applying insights from behavioral economics to policy design*. NBER Working Paper No. 20318, National Bureau of Economic Research, Washington, D.C., 2014.

Madrian, B.C./ Shea D.F. (2001): The power of suggestion: Inertia in 401(k) participation and savings behavior. In: *The Quarterly Journal of Economics*, 116 (4), 1149-87.

Marteau, T./ Ogilvie, D./ Roland, M./ Suhrcke, M./ Kelly, M.P. (2011): Judging nudging: can nudging improve population health?. In: *BMJ – British Medical Journal*, 342, 263-265.

McKenzie, C.R./ Liersch, M.J./ Finkelstein, S.R. (2006): Recommendations implicit in policy defaults. In: *Psychological Science*, 17 (5), 414-420.

McElroy, T./ Seta, J.J. (2003): Framing effects: An analytic–holistic perspective. In: *Journal of Experimental Social Psychology*, 39 (6), 610–617.

Meran, G./ Schwarze, R. (2015): A theory of optimal green defaults. UFZ Discussion Papers No. 6/2015, Helmholtz Zentrum für Umweltforschung, Leipzig, Germany, 2015. URL: https://www.ufz.de/export/data/global/67135_DP_06_2015_Meran_Schwarze.pdf (last time accessed 01.10.2015).

Michalek, G./ Schwarze, R. (2015): Carbon leakage: pollution, trade or politics? In: *Environment, Development and Sustainability*, 17 (6), 1471-1492.

Miehe, R./ Scheumann, R./ Jones, C.M./ Kammen, D.M./ Finkbeiner, M. (2015): Regional carbon footprints of households: a German case study. In: *Environment Development and Sustainability*. Published as online first article: DOI 10.1007/s10668-015-9649-7.

Mills, C. (2015): The heteronomy of choice architecture. In: *Review of Philosophy and Psychology*, 6 (3), 495-509.

Mont, O./ Lehner, M./ Heiskanen E. (2014): *Nudging – A tool for sustainable behavior?* Swedish Environmental Protection Agency – Report 6643, Swedish Environmental Protection Agency, Stockholm, Sweden, 2014. URL: https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6643-7.pdf?pid=14232 (last time accessed: 01.10.2015).

Morewedge, C.K./ Kahneman, D. (2010): Associative processes in intuitive Judgment. In: *Trends in Cognitive Sciences*, 14 (10), 435-440.

Morton, T.H./ Rabinovich, A./ Marshall, D./ Bretschneider, P. (2011): The future that may (or may not) come: How framing changes responses to uncertainty in climate change communications. In: *Global Environmental Change*, 21 (1), 103-109.

Moseley, A./ Stoker, G. (2013): Nudging citizens? Prospects and pitfalls confronting a new heuristic. In: *Resources, Conservation and Recycling*, 79, 4-10.

Oliver, A. (2013): From nudging to budging: using behavioral economics to inform public sector policy. In: *Journal of Social Policy*, 42 (4), 685-700.

Oliver, A. (2015): Nudging, Shoving, and Budging: Behavioral Economic-Informed Policy. In: *Public Administration*, 93 (3), 700-714.

Orbell, S./ Verplanken, B., (2010): The Automatic Component of Habit in Health Behavior: Habit as Cue-Contingent Automaticity. In: *Health Psychology*, 29 (4), 374-383.

Ölander, F./ Thøgersen, J. (2014): Informing Versus Nudging in Environmental Policy. In: *Journal of Consumer Policy*, 37 (3), 341-356.

Park, C.W./ Jun, S. Y./ MacInnis, D. J. (2000): Choosing what I want versus rejecting what I do not want: An application of decision framing to product option choice decisions. In: *Journal of Marketing Research*, 37 (2), 187-202.

Petty R. E./ Brinol, P./ Loersch, C./ McCasslimn M.J. (2009): *The Need for cognition*. In: Leary, M.R./ Hoyle, R.H. [eds.]: Handbook of individual differences in social behavior. Guilford Press, New York, NY, 2009, pp. 318-329.

Petty, R.E./ Cacioppo, J.T. (1981): Issue involvement as a moderator of the effects on attitude of advertising content and context. In: *Advances in Consumer Research*, 8 (1), 20-24.

Petty, R.E./ Cacioppo, J.T./ Schumann, D. (1983): Central and peripheral routes to advertising effectiveness: the moderating role of involvement. In: *Journal of Consumer Research*, 10 (2), 135-146.

Petty, R.E./ Cacioppo, J. T. (1986): *Communication and persuasion: Central and peripheral routes to attitude change*. Springer Publishing, New York, NY, 1986.

Petty R.E./ Wegener, D. (1999): *The Elaboration Likelyhood Model: Current Status and Controversies*. In: Chaiken, S./ Trope, Y. [eds.]: Dual-process theories in social psychology. The Guilford Press, New York, NY, 1999, pp. 41-72.

Pichert, D./ Katsikopoulos, K.V. (2008): Green defaults: Information presentation and pro-environmental behavior. In: *Journal of Environmental Psychology*, 28 (1), 63-73.

Putnam, L. (2015): *Workplace Wellness that Works: 10 Steps to Infuse Well-Being and Vitality into Any Organization*. John Wiley & Sons, Hoboken, NJ, 2015.

Reisch, L./ Hagen, K. (2011): *Kann der Konsumwandel gelingen? Chancen und Grenzen einer verhaltensökonomisch basierten sozialen Regulierung*. In: Schmidt, I./ Ahaus, B. [eds.]: Die Verantwortung des Konsumenten: Über das

Verhältnis von Markt, Moral und Konsum. Campus Verlag, Frankfurt am Main, Germany, 2011, pp. 221-243.

Rogge, K.S./ Reichardt, K. (2013): *Towards a more comprehensive policy mix conceptualization for environmental technological change: a literature synthesis*. Working Paper Sustainability and Innovation S3/2013, Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany, 2013. URL: https://www.econstor.eu/dspace/bitstream/10419/77924/1/749915005.pdf (last time accessed 01.10.2015).

Ronis, D.L./ Yates, F.J./ Kirscht, J.P. (1989): *Attitudes, Decisions, and Habits as Determinants of Repeated Behavior*. In: Pratkanis, A./ Breckler, S.J./ Greenwald, A.G. [eds.]: Attitude, Structure and Function. Lawrence Erlbaum Associates, Hillsdale, NJ, 1989, pp. 213-239.

Rozin, P./ Scott, S./ Dingley, M./ Urbanek, J.K./ Jiang, H./ Kaltenbach, M. (2011): Nudge to nobesity I: Minor changes in accessibility decrease food intake. In: *Judgment and Decision Making*, 6 (4), 323-332.

Salovey, P./ Williams-Piehota, P. (2004): Field Experiments in Social Psychology Message Framing and the Promotion of Health Protective Behaviors. In: *American Behavioral Scientists*, 47 (5), 488-505.

Scheufele, D.A./ Tewksbury, D. (2007): Framing, Agenda Setting, and Priming: The Evolution of Three Media Effects Models. In: *Journal of Communication*, 57 (1), 9-20.

Schultz, P.W./ Nolan, J.M./ Cialdini, R.B./ Goldstein, N.J./ Griskevicius, V. (2007): The constructive, destructive, and reconstructive power of social norms. In: *Psychological Science*, 18 (5), 429-434.

Schurr, P.H. (1987): Effects of gain and loss decision frames on risky purchase negotiations. In: *Journal of Applied Psychology*, 72 (3), 351-358.

Science and Technology Committee (2011): *House of Lords - Science and Technology Select Committee 2nd Report of Session 2010-12 – Behavior Change*. House of Lords Paper 179, House of Lords, London, UK, 2011. URL: http://www.publications.parliament.uk/pa/ld201012/ldselect/ldsctech/179/179.pdf (last time accessed 01.10.2015).

Selinger, E./ Whyte, K. (2011): Is There a Right Way to Nudge? The Practice and Ethics of Choice Architecture. In: *Sociology Compass*, 5 (10), 923–935.

Selinger, E./ Whyte, K. (2012): What counts as Nudge? In: *American Journal of Bioethics*, 12 (2), 11-31.

Simon, H.A./ Chase, W.G. (1973): Skill in Chess. In: *American Scientist*, 61 (4), 394-403.

Skov, L.R./ Lourenço, S./ Hansen, G.L./ Mikkelsen, B.E./ Schofield, C. (2013): Choice architecture as a means to change eating behavior in self-service settings: a systematic review. In: *Obesity Reviews*, 14 (3), 187-196.

Sunstein, C.R. (2014): *Nudge vs. Shoves*. Regulatory Policy Program Working Paper RPP - 2014-09. Mossavar-Rahmani Center for Business and Government, Harvard Kennedy School, Harvard University, Cambridge, MA, 2014. URL: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2390120 (last time accessed 01.10.2015).

Sunstein, C.R./ Reisch, L. (2013): Automatisch Grün: Verhaltensökonomik und Umweltschutz. In: *ZfU - Zeitschrift für Umweltpolitik und Umweltrecht*, 36 (2), 119-147.

Thaler, R.H./ Sunstein, C. R. (2008*): Nudge – Improving Decisions About Health, Wealth, and Happiness*. Yale University Press, New Haven, CT, 2008.

Tenbrunsel, A./ Messick, D.M. (1999): Sanctioning Systems, Decision Frames, and Cooperation. In: *Administrative Science Quarterly*, 44 (4), 684-707.

United States Environmental Protection Agency (EPA). Overview of greenhouse gases. URL:
http://www3.epa.gov/climatechange/ghgemissions/gases/n2o.html (last time accessed 03.10.2015).

Vandenbergh, M.P./ Barkenbus, J./ Gilligan, J.M. (2008): Individual carbon emissions: the low-hanging fruit. In: *UCLA Law Review*, 55 (6), 1701-1758.

Wansink, B. (2004): Environmental factors that increase the food intake and consumption volume of unknowing consumers. In: *Annual Review of Nutrition*, 24, 455-479.

Wilson, T.D./ Schooler, J.W. (1991): Thinking too much: Introspection can reduce the quality of preferences and decisions. In: *Journal of Personality and Social Psychology*, 60 (2), 181-192.

Willis, L.E. (2013): When nudges fail: Slippery defaults. In: *The University of Chicago Law Review*, 80 (3), 1155-1229.

Wisdom J./ Downs, J.S./ Loewenstein, G. (2010): Promoting Healthy Choices: Information versus Convenience. In: *American Economic Journal: Applied Economics*, 2 (2), 164-178.

Wortman, C.B./ Brehm, J.W. (1975): Responses to uncontrollable outcomes: An integration of reactance theory and the learned helplessness model. In: *Advances in Experimental Social Psychology*, 8, 277-336.

Appendix to chapter 6: Supplemental material for “Chapter 6: Nudging as a new “soft” tool in environmental policy – An analysis based on insights from cognitive and social psychology”

Chapter 6 – Appendix a) Examples of type 1 and type 2 nudges

<table>
<tr><th colspan="2">Type 1 nudge</th><th colspan="2">Type 2 nudge</th></tr>
<tr><td>General application →</td><td>Extensions to environmental domain</td><td>General application →</td><td>Extensions to environmental domain</td></tr>
<tr><td>1. Visual illusions:
- traffic control: they make drivers believe they are going faster than they really are (see e.g., Thaler and Sunstein 2008)</td><td>
- Support for fuel-efficient driving: speed reduction on highways (driving at 90 km/h reduces fuel consumption by 20% compared to 120 km/h),[51] (Thaler and Sunstein 2008)</td><td>1. ‘Social’ nudges:
- applied in several different domains to guide behaviour.

References to positive descriptive (practiced) and / or injunctive (approved of) norms

Using social comparisons</td><td>
- prevention of timber theft and littering in the forest (Cialdini 2003)

- water and energy conservation through multiple use of towels by hotel guests (Goldstein et al. 2008)

- energy conservation by sending reports indicating a household’s own energy usage and a comparable neighborhood household’s energy usage (see e.g., Schultz et al. 2007; Allcott 2011; Costa and Kahn 2013, Ayres et al. 2013)</td></tr>
</table>

[51] See also http://eartheasy.com/move_fuel_efficient_driving.html.

2. Physical and ambient features of the choice environment • Positioning of objects: - Obesity prevention, propagation of healthy nutrition: healthy food is presented in visible and easily accessible places in canteens, lunch bars and shops (see e.g., Marteau et al. 2011; Rozin et al. 2011; Skov et al. 2013) • Using ambient characteristics: - 'soft lighting' such as candlelight encourages people to stay longer in a restaurant and order additional food (Wansink 2004) - classical music played loudly in public areas and shops deters vandalism and misbehavior among young adults (Hirsch 2007)	- propagation of low-carbon food: placement of vegan dishes and food made from locally grown organic products in visible, accessible places in supermarkets and canteens, see e.g., Reisch and Hagen 2011) - public transportation: improved accessibility by public transportation (more forms of transport operating at shorter intervals) - using ambient techniques to encourage pro-climate consumer choices , e.g., divisions in a shop/ canteen where low-carbon food is sold, (e.g., Wansink 2004), in public transportation etc.	**2. Framing /salience** - Presenting choice in positive or negative terms (based on a typology by Levin et al. 1998): • Framing risky choices: positive framing (emphasis on gain) supports risk aversion, while negative framing (emphasis on loss) encourages risk taking. - bargaining: risk-averse decisions were made more frequently when the emphasis was put on the potential gain; risky behavior was observed more often when potential loss mitigation was stressed (Schurr 1987) • goal frame: positive framing stresses gains from performing an action / negative framing highlights losses resulting from doing nothing. - increasing work productivity by framing performance bonuses in terms of a loss (Hossain and List 2012) - effective healthcare and disease prevention: loss-framed messages increase mammography and HIV test rates; gain framing is very useful for encouraging physical exercise, application of sun screen (Salovey and Williams-Piehota, 2004) • attribute framing: placing emphasis on a particular aspect of an object influences its evaluation - labelling: a product contains 10% fat vs. a product is 90% fat-free (Levin and Gaeth 1988, Levin et al. 1998)	- climate change communication (see e.g., Morton et al. 2011) - presenting inertia/ inaction as a loss: non-adoption of energy-saving behavior and appliances results in a monetary loss (see e.g., Beretti et al. 2013) - eco-labelling: a product has been manufactured using 80% 'grey' coal energy vs. a product has been manufactured using 20% 'green' renewable energy, (Levin et al. 1998)

3a Defaults (Opt-out)		**3. Prompted defaults (people are forced to make an active choice)**	
- Organ donation: organ donation is presented as a pre-defined option (Johnson and Goldstein 2003)	- Promotion of renewable energy: a renewable energy mix is a pre-defined option in an energy contract (see e.g., Pichert and Katsikopoulos 2008, Sunstein and Reisch 2013) - Paper savings: double-sided printing defaults (see e.g., Sunstein and Reisch 2013; Egebark und Ekström 2013) - Heating savings: pre-defined settings on office thermostats (Brown et al. 2013), air conditioning - CO_2 compensation payments: compensation for CO_2 emissions is included in price (Araña and León 2013)	- Retirement savings plans: enforcement of active choice increases enrollment in 401(k) savings plan compared to an opt-in option. This solution is particularly useful when the population has heterogeneous preferences (see e.g., Carroll et al. 2009).	- Paper savings: stickers 'no ads please' half-attached to mail boxes (attach or remove) (Liebig and Rommel 2014)
3b Default size/amount of goods			
- obesity prevention: smaller plate and glass in canteens and lunch bars (Wansink 2004)	- water/ paper conservation: pre-defined amount of water in tap to wash/ paper towel to dry hands		
		4. Intuitive labelling, symbols (***accessible*** information)	
		-obesity prevention, healthy nutrition: traffic light labels on products - green: healthy, yellow: caution recommended, red: unhealthy (Hagen 2010)	- propagation of low-carbon (climate friendly) food: traffic light labels on products (green: low, yellow: moderate, red: high CF compared to other food products) (Hagen 2010).

Tab. 6.2.: Examples of type 1 and type 2 nudges.

(Authors' design; sources see in the table).

Chapter 7: Public-private partnerships, incomplete contracts, and distributional fairness – when payments matter

by Özgür Yildiz
Technische Universität Berlin
Department of Economic Policy and Environmental Economics

(Unpublished manuscript)

Abstract

The German energy sector's transition toward the more distributed production of energy has given rise to various forms of decentralized energy production. Within the framework of decentralized infrastructure, the relation between the involved agents is often characterized by a high degree of social proximity. Thus, the spatial and social closeness usually emphasizes aspects of decision-making such as pro-social behavior that can have significant effects on the involved parties' response to agency problems and their investment incentives.

This essay applies behavioral economics' finding on so-called social preferences to fundamental insights from incomplete contract theory regarding economic agents' investment behavior. Specifically, it will be analyzed how a contractor's investment incentives develop in a public-private partnership setting given incomplete contracts when the contractor disposes of preferences for distributional fairness. It will be shown that the investment incentives of the contractor are significantly different from those of the standard model assuming neoclassical preferences. Another important finding is that in contrast to the standard model in which only the allocation of property rights can set different investment incentives, payments can also influence an economic agent's behavior when social preferences apply as the distribution of payments determines whether the psychological influences of envy or a sense of guilt are affecting the contractor.

Keywords

Incomplete contracts; public-private partnerships; fairness; social preferences; behavioral economics

Acknowledgements
The author would like to thank Prof. Dr. Georg Meran (TU Berlin – Department of Economic Policy and Environmental Economics) for valuable comments on the manuscript and support with the Wolfram Mathematica software application. The author would also like to thank the Volkswagen Foundation for the funding of his research on behavioral economics within the energy sector.
Furthermore, the author would also like to thank an anonymous text editor at Cambridge Proofreading LLC (http://proofreading.org/) for language-editing.

List of abbreviations in chapter 7

PPP	public-private partnership
PPPs	public-private partnerships

List of symbols in chapter 7

α	parameter reflecting the extent of the aversion against disadvantageous distributional inequality ("sense of envy")
B	(gross) benefit to society from running a specific infrastructure
B_0	fixed basic benefit amount that arises when an infrastructure is finished
β	parameter reflecting the extent of the aversion against advantageous distributional inequality
C	total costs from running a specific infrastructure, borne by the actor who operates the infrastructure
C_0	fixed basic cost that accrues when operating the infrastructure
c	productivity parameter that has an influence on unproductive investments within the cost function C of operating the infrastructure
$c(e)$	function of unproductive investments that has an impact on the overall costs C of operating the infrastructure (only relevant in the Hart (2003) model)
e	unverifiable amount of unproductive investment by the contractor
e^*	first-best/ optimal amount for unproductive investment by the contractor
$e^{\max}$	possible maximum amount of unproductive investments contractor can make in a specific scenario
$\hat{e}$	unproductive investments made by the contractor in the unbundling case without social preferences (as in the Hart (2003) model)
$\hat{\hat{e}}$	unproductive investments made by the contractor in the PPP case without social preferences (as in the Hart (2003) model)
$\hat{e}_{PPPsp}$	unproductive investments made by the contractor in the PPP case when social preferences are relevant
$\hat{e}_{Usp}$	unproductive investments made by the contractor in the unbundling case when social preferences are relevant
γ	productivity parameter that has an influence on productive investments within the cost function C of operating the infrastructure

$\gamma(i)$	function of productive investments that has an impact on the overall costs C of operating the infrastructure (only relevant in the Hart (2003) model)
i	unverifiable amount of productive investment by the contractor
i^*	first-best/ optimal amount for productive investment by the contractor
$i^{\max}$	possible maximum amount of productive investments contractor can make in a specific scenario
$\hat{\imath}$	productive investments made by a contractor in the unbundling case without social preferences (as in the Hart (2003) model)
$\hat{\hat{\imath}}$	productive investments made by the contractor in the PPP case without social preferences (as in the Hart (2003) model)
$\hat{\imath}_{PPPsp}$	productive investments made by the contractor in the PPP case when social preferences are relevant
$\hat{\imath}_{Usp}$	productive investments made by the contractor in the unbundling case when social preferences are relevant
o	productivity parameter that has an influence on unproductive investments within the gross benefit function of the society B
$o(e)$	function of unproductive investments that has an impact on the overall benefit to society B (only relevant in the Hart (2003) model)
ω	productivity parameter that has an influence on productive investments within the gross benefit function of the society B
$\omega(i)$	function of productive investments that has an impact on the overall benefit to society B (only relevant in the Hart (2003) model)
P_0	fixed payment for the construction of the infrastructure
t	point in time with $t = [0, 1, 2]$
$TC_{contr.}$	total construction costs of the contractor
$U_{C_{PPP-SP}}$	utility function of the contractor in the PPP case, with social preferences
$U_{C_{PPP-SP},P1}$	utility function of the contractor in the PPP case, when public authority's net payoffs are higher than the contractor's (i.e. the "envy" case)
$U_{C_{PPP-SP},P2}$	utility function of the contractor in the PPP case, when public authority's net payoffs are lower than the contractor's (i.e. the "sense of guilt" case)

$U_{C_{UNB-SP}}$ utility function of the contractor in the unbundling case, with social preferences

$U_{C_{UNB-SP},U1}$ utility function of the contractor in the unbundling case, when public authority's net payoffs are higher than the contractor's (i.e. the "envy" case)

$U_{C_{UNB-SP},U2}$ utility function of the contractor in the unbundling case, when public authority's net payoffs are lower than the contractor's (i.e. the "sense of guilt" case)

$U_{Soc.}(e,i)$ the society's utility function (net benefit), reproducing the economic exchange between contractor and public authority and depending on the contractor's investments e and i

$V_{C_{PPP}}$ net payoffs of the contractor in the PPP case; equal to the contractor's utility function without social preferences

$V_{C_{UNB}}$ net payoffs of a contractor in the unbundling case, equal to the contractor's utility function without social preferences

$V_{PA_{PPP}}$ net payoffs of the public authority in the PPP case

$V_{PA_{UNB}}$ net payoffs of the public authority in the unbundling case

7.1. Introduction

The transition of the energy sector toward the broader use of renewable energy sources has introduced new technologies, regulatory regimes, and business models; and led to a reconfiguration of governance strategies within urban as well as rural areas (Monstadt 2007).[52] These governance patterns involve a variety of stakeholders – for example, the administration as strategy and framework setter, local authorities that implement regional energy policy, established energy suppliers trying to adapt their business model, new energy companies entering the market, institutional and strategic investors, the industry as one of the main consumers, and citizens who are nowadays not only another important group of consumers but also urged to play a bigger role in energy decisions through various forms of participation mechanisms (e.g. Devine-Wright 2005). Against this background, strategies and governance approaches such as the distributed generation of energy (e.g. Pepermans et al. 2005; Alanne and Saari 2006; Karger and Hennings 2009), re-municipalization of existing infrastructure (e.g. Hall et al. 2013; Becker et al. 2015), and development of business models allowing for the financial participation of citizens (e.g. Yildiz 2014; Höfer and Rommel 2015) have gained particular attention.

Among these strategies, public-private partnerships (PPPs) are also a relevant governance approach to realizing renewable energy projects (e.g. Martins et al. 2011). Particularly for developing countries, PPPs promise to provide relief to constraints such as insufficient government investments due to limited public budgets, difficulties in mobilizing financial resources among citizens, or limited interest from the private sector due to project finance risks, since PPPs can allocate project risks between several parties (Sovacool 2013). Decisive for the functioning and performance of public-private partnership (PPP) relationships are complex contractual agreements between the involved parties. Here, the institutional framework given by the underlying contracts affects the involved parties' behavior and investment incentives, and therefore determines the agreements' efficiency (Saussier et al. 2009).

The new institutional economics literature, particularly the strand on property rights theory, dedicates substantial work to the question of the design of the institutional setting of PPPs and its effect on the behavior of actors involved in a PPP (e.g., Hart et al. 1997; Shleifer 1998; Hart 2003). This essay contributes to this strand of litera-

[52] For further reading on socio-technical transitions such as the transition of the energy sector, see e.g., Smith et al. (2005), Meadowcroft (2009), and Foxon et al. (2010).

ture by analyzing the investment behavior of involved parties through a theoretical analysis model.

The distinctive feature of the approach presented here is the link to insights from behavioral economics. According to this research strand, some economic agents dispose of a preference set that is different from the assumptions of neoclassical economics, that is, their behavior is determined by so-called social preferences (e.g. Fehr and Schmidt 1999). By including preferences for distributional fairness among involved parties in the analysis, the model presented here aims to simulate a preference set that might for example be relevant in the context of decentralized infrastructure which is the result of tendencies in the renewable energy sector toward a more dispersed generation approach. Therefore, this paper relates to prior work from Fehr et al. (2008) who theoretically analyzed entities that are organized as partnerships such as law offices, consulting companies, and advertising agencies.

In order to analyze the effects of preferences for distributional fairness in PPPs, this essay is structured as follows: the following section provides an overview on fundamental insights from incomplete contract theory and its applications to PPPs, and describes briefly central findings from behavioral economics in order to provide a rationale on how to extend incomplete contract theory. Section 7.3. introduces the model, then in section 7.4. the analysis is conducted. Finally, this paper ends with concluding remarks and suggestions for further research.

7.2. Literature review

Economic theory offers a large number of explanatory models and analytical frameworks to address the various complex exchange processes that are subsumed under the term *economy* (Buchanan 1984). One of the most prominent domains within economic theory is the analysis of economic exchange through different organizational settings. Dating back to the seminal work of Ronald Coase (1937), often referenced under the headword “Theory of the Firm” numerous authors have analyzed and discussed coordination mechanisms ranging from market transactions to hierarchically organized entities (e.g. Alchian and Demsetz 1972; Williamson 1975). In this context, central questions arise about the reasons for the existence and use of specific coordination mechanisms given a specific economic exchange. Further questions address the effects of an institutional setting (e.g. the specification of property rights) on an economic agent's behavior within a specific organizational framework (Jensen and Meckling 1976).

The latter subject is particularly prominent in the literature under the name of incomplete contract theory. Sanford Grossman and Oliver Hart (1986) were among the first to analyze the relation between contracts, contractual incompleteness, the allocation of property rights, and the effects of this allocation on an economic agent's investment incentives. As it is almost impossible to write a contract that includes subject terms for all possible future states of nature, the allocation of property rights is a crucial element. Property rights assign control in those cases where the contract is not specified. Hence, in cases where the so-called hold-up problem[53] prevents economic agents from making investments, the allocation of property rights provides investment incentives for the owner. To sum up, the general finding from incomplete contract theory is that the economic agent "*whose investments are more important (in the sense of their marginal impacts on the default payoffs) should be the owner*" (Schmitz 2001: 11) of all assets relevant to the economic exchange. Through this allocation, a second-best equilibrium can be realized (e.g., Grossman and Hart 1986; Hart and Moore 1990; Hart 1995; Schmitz 2001).

The rationale underlying incomplete contract theory has also been applied to the question of privatization and PPPs (e.g., Laffont and Tirole 1991; Schmidt 1996; Hart et al. 1997; Hart 2003; see Schönfeld (2011) for a more detailed list with further explanations on the respective models). A general statement on theoretical insights on the allocation of property rights in the context of privatization and PPPs is difficult as the various models include specific scenarios with specific assumptions. Examples are the focus on the provision of public goods through PPPs (e.g. Besley and Ghatak 2001; Francesconi and Muthoo 2006) and the effects of various organizational models on the costs and service quality when realizing and operating infrastructure (Hart et al. 1997; Chalkley and Malcomson 1998; Hart 2003). Though a vague conclusion

---

[53] The so-called hold-up problem describes a problem set in which an economic agent does not invest efficiently in an economic exchange. Short-term contracts and contractual incompleteness can prevent economic agents from making relation-specific investments as they fear that their share in the economic exchange's rents could be extracted by an opportunistically acting exchange partner who ex-post (i.e. after realizing the economic exchange that was agreed on in a contract) demands re-negotiations. In general, ex-post negotiations on the allocation of the exchange's rents would be efficient according to the Coase theorem (see e.g. Coase 1960 and Schweizer 1988 for necessary conditions for the Coase theorem to hold) but with the threat of being exploited, strategies to incentivize parties to join a relationship ex-ante have to be developed. In this context, the allocation of property rights represents a measure to induce ex-ante efficient investment incentives for an economic agent and to join an economic relationship as these property rights determine the bargaining power in the ex-post negotiations (Schmitz 2001).

is that the right to build and operate infrastructure leads to the internalization of the costs of operation by a contractor. Hence, a contractor would put significant efforts in reducing operating costs (and service quality) so that an ordering party has to consider to which extent it can specify the service quality. If the ordering party (i.e. the public authority) can specify well the required service quality, then it should assign both, construction and operation, to one party (Schönfeld 2011).

The previous descriptions highlighted the importance of property rights in an incomplete contract setting in which ownership serves as a device to respond to the threat of opportunistic behavior. Underlying to this threat are the assumptions from neoclassical economics that have their origin in a set of a priori notions on the behavior of agents opposed to an economic problem (e.g., an exchange with other agents). One central characteristic of this theory is that economic agents evaluate all existing (action) alternatives by the utility they expect from the outcomes of a specific decision whereby the utility is exclusively determined by monetary payoffs. Then, economic agents always decide for the alternative that maximizes their expected utility (Simon 1998). With recent trends toward a broader diffusion of experimental methods in economics and the growing influence of insights from other disciplines, particularly the cognitive sciences, the viewpoint is increasingly supported that the explanatory and predictive power of economic analysis can be improved by extending the standard assumption set from neoclassical economics. This development has led to the establishment of so-called behavioral economics, which defines its assumptions according to evidence generated by experiments, field studies, and research methods from cognitive sciences such as brain scans (Camerer and Loewenstein 2004).

An important strand within behavioral economics addresses the question of an economic agent's utility assessment and influencing factors besides monetary payoffs. According to this perspective, findings from experimental game theory (Roth et al. 1981; Güth et al. 1982; Binmore et al. 1985) suggest that some (but not all) economic agents do not behave in a self-interest maximizing manner but are also influenced by behavioral patterns such as reciprocity (e.g. Rabin 1993), altruism (e.g. Khalil 2004), or preferences for distributional fairness (e.g. Fehr and Schmidt 1999) (Fehr and Schmidt 2006). These patterns, so-called social preferences, are dependent on the context of the economic exchange. The framework of the exchange determines the character of social interactions, the economic agents' scope of action, and the way in which information is processed. Thus, in market-like organizational contexts in which relationships are characterized by rather loose personal contacts, social preferences play a subordinated role. In contrast, social interactions are rather tight in non-market settings so that social preferences are more likely to influence an economic agent's utility assessment and consequently his behavior (Bowles 1998).

The insights on social preferences are latterly incorporated into incomplete contract theory in order to analyze the investment incentives of ownership in contexts that are characterized by strong social ties between involved actors. In this regard, findings from theoretical and experimental analysis reveal that among agents with social preferences, ownership allocation schemes set different incentives than those in the standard model – that is, joint ownership sets higher incentives than concentration of ownership (Fehr et al. 2008), Findings in the context of PPPs that include insights on social preferences do not exist so far. However, actual business models and governance approaches in the energy sector (e.g. decentralization, citizen participation schemes) provide a framework in which social preferences might be relevant. Hence, the following section introduces a model in which the impact of social preferences on investment behavior in a PPP setting is analyzed.

7.3. The model

The model presented here has its roots in the Hart (2003) model in order to analyze the effects of different ownership structures on the costs and benefits of PPPs. In fact, the presented model extends Hart's (2003) model by including preferences for distributional fairness. The scenario modeled here takes place in a decentralized context. As a consequence, a socially proximate relationship between the economic agents is assumed so that the involved agents dispose of preferences for distributional fairness (see also section 7.2. for a more detailed rationale to include social preferences in the analysis).

As in the original model of Hart (2003) two actors – a contractor (e.g., a construction firm) and an ordering party (e.g. the public authority) – are involved in an economic exchange. The purpose of their exchange is the construction and, as an additional option, the operation of a specific service (e.g., infrastructure, or a prison as in Hart's (2003) model, etc.).[54] Accordingly, the time line (**Fig.1.**) covers three dates: the date when the underlying contract between the contractor and the ordering party is agreed

[54] In the following, the model will describe, analyze, and discuss a PPP scenario. Therefore, the wording is adapted to this purpose, i.e. the public authority is set as the "ordering party" and the underlying "service" is the construction (and the operation) of an infrastructure project.

on and signed (t=0), the date when the underlying service with its basic characteristics is delivered by the contractor (t=1), and a final date that marks the end of the operational phase (t=2) (Hart 2003).

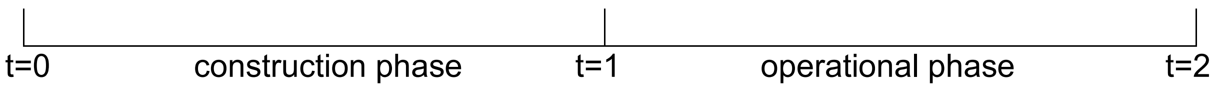

Fig.7.1.: Time line of the analyzed economic exchange.
(Source: Author’s design, adapted from Hart 2003).

The (construction) contract that is underlying to the provision of the infrastructure is incomplete (see e.g. Grosman and Hart 1986). That means the contract parties define basic elements of the required service but the constructor can still modify other specific details related to his service without violating the agreement between both parties. These specific details, $i \geq 0$ being the unverifiable amount of productive investment by the contractor and $e \geq 0$ being the unverifiable amount of unproductive investment by the contractor, depending on the decision of the constructor, cannot be verified by a third party and consequently cannot be contracted on, and form together the contractor’s total construction cost $TC_{contr.} = i + e$. Furthermore, they are of particular importance as they influence the costs and benefits to society when the infrastructure is in use (Hart 2003). Accordingly, the costs and benefits of the operational phase in this model are defined as follows:

$$B = B_0 + \omega * i - o * e \qquad (7.1.)$$

$$C = C_0 - \gamma * i - c * e \qquad (7.2.)$$

with ω, o, γ, c being strictly positive so that the related terms are linear functions.[55]

Equation (7.1.) represents the (gross) benefit B that a society has from operating the infrastructure, measured in monetary terms. It comprises a fixed basic benefit B_0, a function of productive investments $\omega * i$, and a function of unproductive investments $o * e$. With regard to the benefit to society, productive investments i raise the quality

[55] In the Hart (2003) model, the assumptions $\omega, o, \gamma, c > 0$, $\omega', o', \gamma', c' > 0$, $\omega'', \gamma'', c'' < 0$, and $o'' > 0$ apply. In this model, linear production functions were assumed for the sake of simplicity. As the model aims to show fundamental trends in the contractor’s investment behavior when including social preferences, this simplification avoids problems regarding concavity of the utility function and changes that arise from the variation of the applying psychological effect.

of the service realized through the infrastructure and therefore the benefit to society. In contrast, unproductive investments e reduce the quality of the service and therefore the overall benefit to society. Equation (7.2.) represents the costs C of operating the infrastructure. Here, the components are a fixed amount of basic costs C_0, a function of productive investments $\gamma * i$, and a function of unproductive investments $c * e$. Both types of investment, productive and unproductive investments, reduce the total costs (Hart 2003).

The objective function is to maximize the net benefit of the economic exchange (i.e. the society's net benefit) $U_{Soc.}(e,i)$. Hence, in the first-best scenario i and e are chosen to maximize the following equation:

$$U_{Soc.}(e,i) = B - C - TC_{contr.} = B_0 + \omega * i - o * e - C_0 + \gamma * i * + c * e - i - e \qquad (7.3.)$$

In order to be consistent with the Hart (2003) model, the following additional conditions also apply:

$$\omega + \gamma > 1$$

$$c - o < 1.$$

Hence, we arrive at the socially optimal result (the "first-best") in the corner solutions where $i^* = Max[0; i^{\max}]$ and $e^* = 0$ (Hart 2003).

So far, this model and the related explanations are similar to the Hart (2003) model. The preferences for distributional fairness become important when considering the second-best scenario. The builder's investments cannot be verified and therefore cannot be contracted on. However, the contractor knows the exact amount of his costs i and e. Consequently, the allocation of property rights (i.e., the assignment of the right to operate the infrastructure between $t = 1$ and $t = 2$) has an influence on the contractor's investment behavior (Hart 2003).

In the following, two cases will be distinguished, a first case in which the construction and the operation of the infrastructure are assigned to different actors ("unbundling" case) and another case, in which the infrastructure is operated by the same agent that constructed it ("PPP" case). These two cases are sub-divided into a case that describes the (neoclassical) standard model as in Hart (2003) and a model in which the contractor has preferences for distributional fairness.

7.3.1. The unbundling case

In the unbundling case, the contractor receives a fixed payment P_0 for the construction of the infrastructure and bears the costs for the investments i and e. Hence, his net payoffs (that are equal to his utility) are

$$V_{C_{UNB}} = P_0 - i - e \tag{7.4.}$$

and at date $t = 0$, the contractor's objective is to choose i and e to solve:

$$Max(V_{C_{UNB}}) = Max(P_0 - i - e)\,. \tag{7.5.}$$

The net payoffs of the commanding party (i.e., public authority) include the benefit to society B, the costs of operating the plant C, and the fixed payment P_0. Hence, the public authority's payoffs from operating the plant are:

$$V_{PA_{UNB}} = B - C - P_0 = B_0 + \omega * i - o * e - C_0 + \gamma * i + c * e - P_0 \tag{7.6.}$$

In the original paper of Hart (2003), the net payoff function of the public authority in the unbundling case $V_{PA_{UNB}}$ is slightly different as $P_0 = i + e$ is set. Underlying this equation is the assumption that there is competition in the market for contractors and therefore the public authority can set the fixed price P_0 for the service just high enough to cover the contractor's costs, the investments i and e. However, in this model, it is assumed that there is no competition among contractors. In fact, the context of decentralized infrastructure that is set as a framework of this model reasons that there is only one contractor and consequently no competition. In return, the socially close context of the economic exchange results in preferences for distributional fairness among the involved parties.

Including preferences for distributional fairness changes the utility function of involved agents significantly. For the further course of the analysis, the utility function of the contractor is of particular interest. In reference to Fehr and Schmidt's (1999) approach to including preferences for distributional fairness in an economic agent's utility function, the utility function of a contractor with social preferences $U_{C_{UNB-SP}}$ is as follows:

$$U_{C_{UNB-SP}} = V_{C_{UNB}} - \alpha * \max\{V_{PA_{UNB}} - V_{C_{UNB}}, 0\} - \beta * \max\{V_{C_{UNB}} - V_{PA_{UNB}}, 0\} \tag{7.7.}$$

with α reflecting the extent of the contractor's aversion to disadvantageous distributional inequality (i.e., "envy") and β reflecting the extent of the contractor's aversion to advantageous distributional inequality (i.e., "sense of guilt"). Accordingly, the second term as a whole covers a reduction of the contractor's utility due to disadvantageous distributional inequality, and the third term a reduction of the contractor's utility due to advantageous distributional inequality. As in the Fehr and Schmidt (1999) model, both inequality parameters are $\alpha, \beta \geq 0$ where $\alpha, \beta = 0$ would imply that the contractor has preferences according to the standard (neoclassical) model. Furthermore, it is assumed that $\alpha \geq \beta$, which implies that in social comparisons, the aversion to disadvantageous distributional inequality is at least as high as the sense of guilt that arises when the analyzed agent (i.e., the contractor) is better off than his reference agent (Fehr and Schmidt 1999).[56]

7.3.2. The PPP case

In the PPP case, the contractor is allocated the rights to operate the infrastructure.[57] Hence, the contractor now internalizes the costs of the operation phase C so that his net payoffs assuming standard (neoclassical) preferences (as in Hart 2003) include his fixed payment P_0 and the relevant cost item, the total operational costs $C(e,i)$ and the investments i and e:

$$V_{C_{PPP}} = P_0 - C - i - e = P_0 - C_0 + \gamma * i + c * e - i - e \qquad (7.8.)$$

Accordingly, the public authority's payoffs are determined by the benefit to society of realizing infrastructure B and the fixed compensation P_0 that it has to pay to the contractor for his service to construct the infrastructure:

[56] The Fehr and Schmidt (1999) model makes further assumptions on the inequality parameters. An example is the restriction of the range of the β-parameter to $0 \leq \beta < 1$, which is introduced in order to reflect that $\beta = 1$ implies an economic agent who would throw away some of his monetary payoffs in order to reduce advantageous inequality, which is not very plausible (Fehr and Schmidt 1999). Some of these additional assumptions as well as plausible numeric values for the inequality parameters α and β will be discussed in section 7.4.3.

[57] In Hart's (2003) model, the contractor has either the possibility to operate the infrastructure by himself or sub-contract this service to a sub-contractor. As there is competition on the market of sub-contractors, the payments to the sub-contractor can be set equal to the costs of operating the infrastructure $C = C_0 - \gamma * i - c * e$. In the decentralized context of this model, it is simply assumed that the contractor provides the service by himself. Alternatively, one could also apply the same rationale as in the Hart (2003) model, i.e. the assignment to a sub-contractor, which is chosen among several alternatives in a competitive market.

$$V_{PA_{PPP}} = B - P_0 = B_0 + \omega * i - o * e - P_0 \quad (7.9.)$$

As in the unbundling case, it is also necessary to determine the utility of the contractor, given preferences for distributional fairness. Again, differences regarding the distribution of net payoffs, either advantageous or disadvantageous, have a negative effect on the contractor's utility:

$$U_{C_{PPP-SP}} = V_{C_{PPP}} - \alpha * \max\{V_{PA_{PPP}} - V_{C_{PPP}}, 0\} - \beta * \max\{V_{C_{PPP}} - V_{PA_{PPP}}, 0\} \quad (7.10.)$$

With the necessary net payoffs and utility functions defined, the effects of different ownership structures on the investment behavior of the contractor can now be analyzed.

7.4. Theoretical assessment of contractor behavior given preferences for distributional fairness

In the model of Hart (2003), the public authority has to consider a trade-off when making its decision. In the unbundling case, neither productive investments i nor unproductive investments e are made since the contractor does not internalize the social benefit B nor the costs of the operation phase C. Regarding unproductive investments, $\hat{e} = 0$ corresponds to the first-best solution $e* = 0$. However, $\hat{\imath} = 0$ represents an underinvestment in productive investments as the first-best here is the solution to the first-order condition $\omega'(i*) + \gamma'(i*) = 1$ where $i* > 0$.[58] In the PPP case of Hart's (2003) model, the investment behavior of the contractor is significantly different. As the infrastructure's operating agent, the contractor now internalizes the costs of the operation phase C. Consequently, the contractor now invests in both, productive and unproductive investments. While it is clear that any investment in unproductive terms e is sub-optimal from a social perspective ($\hat{e} > 0 \neq e*$), a look at the first-order conditions ($\gamma'(\hat{\imath}) = 1$) reveals that the investments made in productive invest-

[58] As the Hart (2003) model does not limit its analysis to a setting with linear functions, the first-best is the solution to the first-order condition $\omega'(i*) + \gamma'(i*) = 1$ where $i* > 0$. The analogous solution for the model presented here is $i* = Max[0; i^{\max}]$ (see section 7.3.).

ments are indeed $\hat{i} > 0$ but the amount is lower than in the first-best case (Hart 2003).[59]

According to the first-best solution analysis of the previous paragraph, the derived recommendation for action for public authorities is evident: If the characteristics of the asset underlying the economic exchange (here: the infrastructure) can be well specified and the quality of the service in the operational phase cannot, unbundling seems to be the better option as the PPP case would lead to an overinvestment in unproductive investments e, which has particularly negative consequences for the operational phase in the case that the service provided in the operational phase cannot be specified well or monitored through performance measures. Hence, the rationale for the PPP case is the opposite, that is, a PPP seems to be the better alternative when the service provided in the operational phase can be specified well but there are concerns regarding the specification of the characteristics of the underlying asset (Hart 2003).

In the following, it will be assessed how the contractor will behave, assuming he has preferences for distributional fairness. The analysis of the contractor's behavior given preferences for distributional fairness requires a case-by-case study since both scenarios, advantageous or disadvantageous inequality, cannot apply at the same time when the contractor makes his decision on investment levels. To determine whether the psychological effect from an advantageous or disadvantageous inequality influences the contractor's utility, the net payoffs to the contractor ($V_{C_{PPP}}$ or $V_{C_{UNB}}$) and to the public authority ($V_{PA_{PPP}}$ and $V_{PA_{UNB}}$) have to be compared in the respective cases. Accordingly, the influence of the fixed payment to the contractor P_0 is of high importance. Given that the other fixed components (i.e. C_0 and B_0) are exogenously given and not variable, the following analysis will show that P_0 is the main influence on the involved parties' payoffs. Hence, the payment P_0 for the contractor's services determines which psychological influence applies when deciding on his investment level, and therefore determines the shape of the contractor's utility function.

[59] In the PPP case without preferences for distributional fairness, the second-best solution for the model presented here is the investment combination $\hat{\hat{i}} = Max[0; i^{\max}]$ and $\hat{\hat{e}} = Max[0; e^{\max}]$ assuming that the conditions $\gamma > 1$, and $c > 1$ apply. Hence, the investment amount of productive investments in the PPP case corresponds to the first-best solution which is different from the Hart (2003) model where $i^* > \hat{\hat{i}} > 0$. This is due to the fact that as a consequence of linear utility functions, only corner solutions are obtained.

Furthermore, fundamental to the hypotheses and following analysis in the respective cases is that the productivity parameters are in compliance with the conditions $\omega + \gamma > 1$, $c - o < 1$, $\gamma > 1$, and $c > 1$. These conditions are derived from the standard model of Hart (2003) (see also section 7.3.). Hence, implicitly assuming that these conditions hold in the analysis assures that the results of the model including preferences for distributional fairness are comparable to the standard model's results.
The partial analysis in the appendix will show that the variation in parameters can have a significant influence on the contractor's investment incentives as well. However, a comparison of these results with the Hart (2003) model's results would not be appropriate as in this case, the optima of the Hart (2003) model would change as well.

7.4.1. The unbundling case

7.4.1.1. Case U1 – The public authority's net payoffs are higher than the contractor's in an unbundling setting

Assuming that the public authority's net payoffs are higher than the contractor's net payoffs, i.e. $V_{PA_{UNB}} > V_{C_{UNB}}$, the case of disadvantageous inequality ("envy") is relevant to the contractor when deciding on his investment in $t = 0$ so that the third term of equation (7.7.) is equal to zero. Hence, the contractor's utility function is:

$$U_{C_{UNB-SP},U1} = V_{C_{UNB}} - \alpha * \{V_{PA_{UNB}} - V_{C_{UNB}}\} \qquad (7.11.)$$

By substituting $V_{C_{UNB}}$ with equation (7.4.) and $V_{PA_{UNB}}$ with (7.6.), the contractor's utility function arrives at the following form:

$$U_{C_{UNB-SP},U1} = P_0 - i - e - \alpha * \{B_0 + \omega * i - o * e - C_0 + \gamma * i + c * e - P_0 - P_0 + i + e\} \qquad (7.12.)$$

where $V_{PA_{UNB}} > V_{C_{UNB}}$, i.e. $B_0 + \omega * i - o * e - C_0 + \gamma * i + c * e - P_0 > P_0 - i - e$, which is equivalent to $B_0 + \omega * i - o * e - C_0 + \gamma * i + c * e + i + e > 2P_0$.

Hence, the psychological effect of disadvantageous inequality is relevant if the difference of the gross benefit to society B plus the invested amount of productive and unproductive investments minus the costs of operating the infrastructure C is higher than twice the fixed payment to the contractor P_0.

In order to analyze the overall effect of preferences for distributional fairness on the contractor's utility and his investment incentives, a partial analysis of the effects of the respective investments on the contractor's utility is useful. Therefore, equation (7.12.) is differentiated with respect to i and e:

$$\begin{aligned} &\frac{\partial U_{C_{UNB-SP},U1}}{\partial i} = -1 - \alpha * \{\omega + \gamma + 1\} \\ \Leftrightarrow \quad &\frac{\partial U_{C_{UNB-SP},U1}}{\partial i} = -1 + \alpha * \{-\omega - \gamma - 1\} \end{aligned} \tag{7.13.}$$

and

$$\begin{aligned} &\frac{\partial U_{C_{UNB-SP},U1}}{\partial e} = -1 - \alpha * \{c - o + 1\} \\ \Leftrightarrow \quad &\frac{\partial U_{C_{UNB-SP},U1}}{\partial e} = -1 + \alpha * \{o - c - 1\} \end{aligned} \tag{7.14.}$$

<u>Hypothesis U1:</u>

In the unbundling case, the results of the Hart (2003) model are basically duplicated, i.e., the optimal combination of investments is $(\hat{i}_{Usp} = 0; \hat{e}_{Usp} = 0)$ *when effects from disadvantageous distributional inequality apply. However, there can also apply a scenario (of productivity parameters) in which the optimal combination of investments includes unproductive investments, i.e.* $(\hat{i}_{Usp} = 0; \hat{e}_{Usp} > 0)$ *.*

<u>Argument U1:</u>

From the results of the standard model as well as from equations (7.4.) and (7.11.), we see that any productive or unproductive investment will reduce the contractor's net payoffs. This implies that from the perspective of his own net payoffs, the contractor has no incentive to make either productive or unproductive investments.

Consequently, the only way for the contractor to have an incentive to invest in the unbundling case with a sense of envy initially applying is if there is a combination of investments whereby the increase in the utility through the psychological effect covers all losses from net payoffs. In order to realize this, there must be a combination of productivity parameters in which this effect is induced.

From equation (7.12.) as well as from the partial analysis in equation (7.13.) on the effects of an investment in i on the distributional inequality, we know that there is no combination of productivity parameters in which the contractor has an incentive to invest in i from a partial perspective. Any productive investment i will increase the distributional inequality and therefore intensify the negative psychological influence on the contractor's utility. Thus, the psychological effect from an investment in i will always be negative.

In contrast, we see from the equations (7.12.) and the partial analysis in equation (7.14.) that there exists a combination of productivity parameters where an investment in e will reduce the distributional inequality among the involved parties and induce a positive psychological effect. If this positive psychological effect on the contractor's utility is higher than the negative effect of an investment in e that arises due to the reduction of the contractor's net payoffs, then the contractor will invest a positive amount in unproductive investments e so that the combination of optimal investments is $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} > 0)$.

Technically speaking, unproductive investments serve in this case as a regulative measure in order to reduce the disadvantageous distributional inequality from the perspective of the contractor between him and the public authority. Consequently, these investment incentives are only relevant as long as the psychological effect from a sense of envy applies, i.e., as long as $V_{PA_{UNB}} > V_{C_{UNB}}$. Furthermore, we see from equations (7.12.) and (7.14.) that unproductive investments e can only serve as a regulative measure when the negative effect from an investment in e on the society's gross benefit B, which is determined by the productivity parameter o, is sufficiently high. Accordingly, the parameter o must fulfill the condition $o > \frac{1}{\alpha} + (1+c)$, which is derived from equation (7.14.). This condition is compatible with the parameter assumptions of the Hart (2003) model (see second to last paragraph in section 7.4.) so that the optimal investment combination $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} > 0)$ is a realizable solution in which differences from the Hart (2003) model only stem from including preferences for distributional fairness in the analysis.

For all other parameter scenarios, the combination of optimal investments in the unbundling case when a sense of envy applies is $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} = 0)$, i.e., the envious contractor reproduces the behavior of a contractor where social preferences do not apply.■

7.4.1.2. Case U2 – The public authority's net payoffs are lower than the contractor's in an unbundling setting

Assuming that the public authority's net payoffs are lower than the contractor's net payoffs (i.e. $V_{C_{UNB}} > V_{PA_{UNB}}$), the case of advantageous inequality ("sense of guilt") is relevant to the contractor at the point of decision so that the second term of equation (7.7.) is equal to zero. Now, the contractor's utility function is:

$$U_{C_{UNB-SP},U2} = V_{C_{UNB}} - \beta * \{V_{C_{UNB}} - V_{PA_{UNB}}\} \qquad (7.15.)$$

Here again, $V_{C_{UNB}}$ can be substituted with equation (7.4.) and $V_{PA_{UNB}}$ with (7.6.) so that the contractor's utility function is:

$$U_{C_{UNB-SP},U2} = P_0 - i - e - \beta * \{P_0 - i - e - B_0 - \omega * i + o * e + C_0 - \gamma * i - c * e + P_0\} \qquad (7.16.)$$

where $V_{C_{UNB}} > V_{PA_{UNB}}$, i.e. $P_0 - i - e > B_0 + \omega * i - o * e - C_0 + \gamma * i + c * e - P_0$, which is equivalent to $B_0 + \omega * i - o * e - C_0 + \gamma * i + c * e + i + e < 2P_0$.

In order to assess the investment incentives of the contractor in case U2, equation (7.16.) is differentiated with respect to i and e:

$$\begin{aligned} &\frac{\partial U_{C_{UNB-SP},U2}}{\partial i} = -1 - \beta * \{-1 - \omega - \gamma\} \\ \Leftrightarrow \; &\frac{\partial U_{C_{UNB-SP},U2}}{\partial i} = -1 + \beta * \{1 + \omega + \gamma\} \end{aligned} \qquad (7.17.)$$

and

$$\begin{aligned} &\frac{\partial U_{C_{UNB-SP},U2}}{\partial e} = -1 - \beta * \{-1 + o - c\} \\ \Leftrightarrow \; &\frac{\partial U_{C_{UNB-SP},U2}}{\partial e} = -1 + \beta * \{c - o + 1\} \end{aligned} \qquad (7.18.)$$

<u>**Hypothesis U2:**</u>

In the unbundling case, when effects from advantageous distributional inequality apply and the productivity parameters are consistent with the Hart (2003) model, then *only one equilibrium can exist where the contractor invests in productive investment and omits making unproductive investments, i.e.,* $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$.[60]

Hence, the result when psychological effects from an advantageous distributional inequality apply is significantly different from the Hart (2003) model, i.e., $(\hat{\imath} = 0; \hat{e} = 0)$, *and can even reach the first best, i.e.,* $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$, *with* $\hat{\imath}_{Usp} = i^* = Max[0; i^{\max}]$ *if the differences in net payoffs are high enough that the contractor has to invest the maximal possible amount of productive investments in order to reduce the advantageous distributional inequality.*

Argument U2:

As the net payoffs do not change when the nature of the psychological effect changes, the contractor's net payoffs remain the same and will still decrease for every investment in i and e. Hence, again the psychological effect determines whether the contractor has an incentive to invest.

Accordingly, it can be seen from equations (7.16.) and (7.17.) that the negative psychological effect will be reduced in any case through productive investments i as the condition $\beta^*\{1+\omega+\gamma\} > 0$ holds for any combination of parameters $\gamma, \omega > 0$. Technically speaking, the second term in equation (7.17.) implies that productive investments will reduce the advantageous inequality in payoffs in any case. Now, in order to induce incentives to invest, the beneficial effect on the contractor's utility from reducing the distributional inequality must cover the losses in net payoffs from an investment in i, i.e., $\beta^*\{1+\omega+\gamma\} > 1$ must hold. As elaborated earlier (e.g., second to last paragraph in section 7.4.), it is assumed that the conditions $\omega + \gamma > 1$ and $\gamma > 1$ hold in order to provide a parameter set that is comparable to the Hart (2003) model. Thus, we know that if $\beta > 0.5$, then the condition $\beta^*\{1+\omega+\gamma\} > 1$ will be met. In this regard, we know from the seminal essay of Fehr and Schmidt (1999) on the effects of

60 Theoretically, various combinations of optimal investments can exist, depending on the productivity parameters. Here, possible optima are the combinations $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} = 0)$, $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} > 0)$, and in a special case a scenario where any combination $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} > 0)$ that implies a psychological effect equal to zero is optimal. However, the necessary combination of parameters leading to these investments is incompatible with the parameter values that underlie the Hart (2003) model and therefore remain disregarded.

distributional fairness within an economic exchange that "$\beta = 0.5$ *implies that player i is just indifferent between keeping one dollar to himself and giving this dollar to player j*" (Fehr and Schmidt 1999: 824). Consequently, it can be derived that in order to simulate a fair-minded contractor, a parameter value of $\beta > 0.5$ has to be assumed so that it is consequential that a fair-minded contractor who "suffers" from advantageous inequality will make productive investments $\hat{\imath}_{Usp} > 0$ as long as his sense of guilt is effective, i.e., as long as $V_{C_{UNB}} > V_{PA_{UNB}}$.

The analysis of unproductive investments is analogous. As the effect from an investment in e on the contractor's net payoffs is negative, the psychological effect must cover these losses. Thus, from equation (7.18.) we see that $c > \dfrac{1}{\beta} + \{o-1\}$ must hold. In order to assure the similarity with the Hart (2003) model's parameters, also the conditions $c - o < 1$ and $c > 1$ must be met. From the examination of these conditions, it can be seen that for $\beta > 0.5$ there can exist a parameter c that meets the necessary condition $c > \dfrac{1}{\beta} + \{o-1\}$ without violating the other conditions $c - o < 1$ and $c > 1$. Thus, from a partial perspective, the contractor would <u>theoretically</u> have an incentive to make unproductive investments, i.e., $\hat{e}_{Usp} > 0$ as long as $V_{C_{UNB}} > V_{PA_{UNB}}$.

For the assessment of the overall investment incentives, both partial effects have to be compared. Possible optima can theoretically include the combinations $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$, $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} > 0)$, $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} = 0)$, and in a special case a scenario in which both investment types have the same effect on the contractor's utility, and therefore any combination of $(\hat{\imath}_{Usp} \geq 0; \hat{e}_{Usp} \geq 0)$ that completely eliminates the overall psychological effect is optimal.

Among these theoretically possible combinations $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$ is the only realizable optimum given the restrictions on the parameters that arise from the analogy to the Hart (2003) model. The rationale is as follows:

a) For the combination $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$ to be the optimal solution, the effect on the contractor's utility from reducing the negative psychological influence through productive investments i must be in a first step higher than the reduction of the contractor's net payoffs. This is the case as it was shown in the course of the partial analysis above for any combination of parameters that is consistent with the Hart (2003) model.

In addition the effect from reducing the psychological influence through productive investments in i must be higher than the effect of unproductive investments on the psychological influence, i.e. $\beta * \{c-o+1\} < \beta * \{1+\omega+\gamma\}$. This condition is equivalent to $c-o<\omega+\gamma$. As the right side is $\omega+\gamma>1$ as in the Hart (2003) model and the left side of the inequation is $c-o<1$, the necessary condition $\beta * \{c-o+1\} < \beta * \{1+\omega+\gamma\}$ is met for any combination of parameters. Hence, there can exist an optimal investment combination with $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$. Here, the exact amount of $\hat{\imath}_{Usp}$ depends on the difference in payoffs between both agents. If the difference, which depends at the point of decision on the payment to the contractor P_0, is high enough, it can even result in an optimal investment combination $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$ where the contractor will invest $\hat{\imath}_{Usp} = i^* = Max[0; i^{\max}]$. Hence, the first-best will be realized.

b) The combination $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} = 0)$ is not feasible as an optimal solution as the contractor always has incentives to invest $\hat{\imath}_{Usp} > 0$ in any case (see above).

c) For the combination $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} > 0)$ to be the optimal solution, the effect on the contractor's utility from reducing the negative psychological influence through unproductive investments must be higher than the effect of productive investments on the psychological influence. Hence, the parameters must meet the condition $\beta * \{c-o+1\} > \beta * \{1+\omega+\gamma\}$, which is equivalent to $c-o>\omega+\gamma$.
As was shown in bullet point a) of this section, this condition cannot hold as $\omega+\gamma>1$ and $c-o<1$ must be met in order to be compliant with the Hart (2003) model. Thus, $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} > 0)$ is not realizable.

d) The third theoretically possible combination is a special case where both psychological influences have exactly the same effect on the contractor's utility so that any combination of $(\hat{\imath}_{Usp} \geq 0; \hat{e}_{Usp} \geq 0)$ that eliminates the psychological effect is optimal. Accordingly, the necessary parameter combination for this scenario to be realized is $\beta * \{c-o+1\} = \beta * \{1+\omega+\gamma\}$. Here again, we know that this result cannot hold as $\omega+\gamma>1$ and $c-o<1$ must be met.

To summarize, the optimal investment $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$ is the only realizable combination. The exact amount of $\hat{\imath}_{Usp} > 0$ can be regulated through payment P_0 to the contractor. The higher the advantageous inequality in payoffs, the more a fair-minded contractor will invest in order to reduce the discrepancy between him and the public authority. Thus, having full information on the productivity parameters and the aversion parameter β, the public authority can choose the payment P_0 so that the first-best result $(\hat{\imath}_{Usp} = i^* = Max[0; i^{\max}]; \hat{e}_{Usp} = e^* = 0)$ will be reached.■

7.4.2. The PPP case

7.4.2.1. Case P1 – The public authority's net payoffs are higher than the contractor's in a PPP setting

As in case U1 (section 7.4.1.1.), it is assumed that the public authority's net payoffs are higher than the contractor's net payoffs, i.e. $V_{PA_{PPP}} > V_{C_{PPP}}$. As a consequence, the case of disadvantageous inequality ("envy" case) is relevant to the contractor at the point of decision so that the third term of equation (7.10.) is equal to zero. Hence, the contractor's utility function is:

$$U_{C_{PPP-SP},P1} = V_{C_{PPP}} - \alpha * \{V_{PA_{PPP}} - V_{C_{PPP}}\}$$

By substituting $V_{C_{PPP}}$ with equation (7.8.) and $V_{PA_{PPP}}$ with equation (7.9.), the contractor's utility function is:

$$U_{C_{PPP-SP},P1} = P_0 - C_0 + \gamma * i + c * e - i - e - \alpha * \{B_0 + \omega * i - o * e - P_0 - P_0 + C_0 - \gamma * i - c * e + i + e\} \tag{7.19.}$$

The relation between the payoffs of the involved agents is $V_{C_{PPP}} < V_{PA_{PPP}}$, i.e. $P_0 - C_0 + \gamma * i + c * e - i - e < B_0 + \omega * i - o * e - P_0$.

In order to have an impression on the effect of investments on the contractor's utility $U_{C_{PPP-SP}}$ from a partial analysis perspective, equation (7.19.) is differentiated with respect to i and e:

$$\frac{\partial U_{C_{PPP-SP},P1}}{\partial i} = \gamma - 1 - \alpha * \{\omega - \gamma + 1\}$$

$$\Leftrightarrow \frac{\partial U_{C_{PPP-SP},P1}}{\partial i} = \gamma - 1 + \alpha * \{\gamma - \omega - 1\}$$

$$\Leftrightarrow \frac{\partial U_{C_{PPP-SP},P1}}{\partial i} = (1+\alpha) * \gamma - 1 + \alpha * \{-\omega - 1\}$$

(7.20.)

and

$$\frac{\partial U_{C_{PPP-SP},P1}}{\partial e} = c - 1 - \alpha * \{1 - c - o\}$$

$$\Leftrightarrow \frac{\partial U_{C_{PPP-SP},P1}}{\partial e} = c - 1 + \alpha * \{c + o - 1\} \quad . \qquad (7.21.)$$

$$\Leftrightarrow \frac{\partial U_{C_{PPP-SP},P1}}{\partial e} = (1+\alpha) * c - 1 + \alpha * \{o - 1\}$$

Hypothesis P1:

In the PPP case, when psychological effects from disadvantageous inequality apply, several optimal investment combinations can result, depending on the productivity parameters, γ, ω, o and c. Assuming that the parameters are consistent with the Hart (2003) model, the possible optima include the combinations $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} = 0)$ (with the first-best combination also being possible), $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} > 0)$, and $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$.

Argument P1:

From the results of the standard model as well as from equation (7.19.), we know that any productive or unproductive investment will increase the contractor's net payoffs as $\gamma * i - i > 0$ and $c * e - e > 0$, i.e., $\gamma > 1$ and $c > 1$. This implies that from the perspective of his own net payoffs, the contractor has an incentive to make the highest possible amount of productive and unproductive investments. Thus, it has to be examined in which way the psychological effect influences this incentive scheme.

From the partial perspective on productive investments i in equation (7.20.), it can be seen that the psychological effect is positive when $\gamma > \omega + 1$. Here, any investment in i will reduce the distributional inequality among the involved parties and therefore raise the contractor's utility so that the contractor has an incentive to make productive investments i as long as $V_{PA_{PPP}} > V_{C_{PPP}}$. In addition, the contractor can also have incentives to make productive investments i despite a negative psychological influence if the increase in net payoffs is higher than the negative psychological effect, i.e., if $\gamma - 1 + \alpha * \{\gamma - \omega - 1\} > 0$.

The partial analysis of unproductive investments is analogous. Here, it can be seen from equation (7.21.) that the psychological effect is positive when $c + o - 1 > 0$. As the parameters are such that they correspond to the standard model (e.g., $c > 1$, $c - o < 1$), this condition will always be met as $c > 1$ and does not violate the Hart (2003) model's conditions as long as $c - o < 1$ so that the contractor will always have an incentive to make unproductive investments e in the PPP case as long as $V_{PA_{PPP}} > V_{C_{PPP}}$ from a partial perspective.

For the analysis of overall investment incentives and the identification of optimal investment combinations, the comparison of the overall effects (net payoffs and psychological effect) is decisive. As the partial analysis revealed from a partial perspective that $\hat{e}_{PPPsp} > 0$ when $c > 1$ and additionally that the contractor always has an incentive to invest in both types of investments from the perspective of his net payoffs, an optimal combination with $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} = 0)$ is not plausible from an overall perspective. Thus, it has to be analyzed whether the combinations $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} = 0)$, $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} > 0)$, and $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$ are realizable.

a) Keeping in mind that the contractor has an incentive to make unproductive investments from a partial perspective, the first combination $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} = 0)$ is only feasible if the parameters are such that the partial effect from a productive investment is higher than the partial effect of an unproductive investment, i.e., if $\gamma - 1 + \alpha * \{\gamma - \omega - 1\} > c - 1 + \alpha * \{c + o - 1\}$, which is equivalent to the condition $\gamma > c + \frac{\alpha}{1+\alpha} * \{o + \omega\}$. This condition is compatible with the parameter set of the Hart (2003) model as the conditions from the standard model for γ to hold are $\gamma > 1$ and $\gamma + \omega > 1$, so that the investment combination $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} = 0)$ is realizable. In addition, the contractor will always invest $\hat{\imath}_{PPPsp} = i^* = Max[0; i^{\max}]$, which implies that if for the parameter γ the condition $\gamma > c + \frac{\alpha}{1+\alpha} * \{o + \omega\}$ holds, then the first-best solution will be achieved.

A combined investment in both types is in this case not relevant, as both psychological effects operate in the same direction but the positive effect from an investment in productive investments is higher. Hence, a combined investment in productive and unproductive investments would not be efficient assuming that the parameters are such that the condition $\gamma > c + \frac{\alpha}{1+\alpha} * \{o + \omega\}$ is fulfilled.

b) Underlying to the combinations $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} > 0)$ and $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$ is that the contractor has incentives to make unproductive investments rather than productive investments, i.e., $\gamma - 1 + \alpha * \{\gamma - \omega - 1\} < c - 1 + \alpha * \{c + o - 1\}$. In contrast to the previous case, the psychological effect from an investment in i can be positive or negative. Thus, an additional distinction is necessary, which will explain why two different optimal combinations can result.
Assuming that the psychological effect from an investment in i is positive, i.e., $\alpha * \{\gamma - \omega - 1\} > 0$, then the rationale is similar to the previous case. Here, the condition $\gamma - 1 + \alpha * \{\gamma - \omega - 1\} < c - 1 + \alpha * \{c + o - 1\}$ must be met, which is equivalent to the condition $c > \gamma + \frac{\alpha}{1+\alpha} * \{-\omega - o\}$. This condition is compatible with the parameter set of the Hart (2003) model as the conditions from the standard model for c to hold are $c > 1$ and $c - o < 1$ so that the investment combination $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} > 0)$ with $\hat{e}_{PPPsp} = Max[0; e^{\max}]$ is also one of the realizable optimal investment combinations implying a "worst-case" investment combination as the maximum amount of unproductive investments is realized while productive investments are omitted.
If the psychological effect of a productive investment i is negative, i.e., $\alpha * \{\gamma - \omega - 1\} < 0$, then the analysis has to focus on the differences in payoffs and the maximum amount of investments that are possible, i.e. $[0; e]$ and $[0; i]$. The necessary condition remains the same, i.e., $c > \gamma + \frac{\alpha}{1+\alpha} * \{-\omega - o\}$ so that the contractor will make unproductive investments e as long as $V_{PA_{PPP}} > V_{C_{PPP}}$. If the disadvantageous difference in payoffs between the contractor and the

public authority is that high enough that the contractor can invest $\hat{e}_{PPPsp} = Max[0; e^{\max}]$ then the optimal combination of investments will be $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} > 0)$. If the contractor cannot invest $\hat{e}_{PPPsp} = Max[0; e^{\max}]$, then the contractor will make productive investments i in order to increase the differences in payoffs. Through this, the contractor can in turn make more unproductive investments. Thus, the optimal combination of investments will be $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$ where in an extreme case the investment levels $\hat{\imath}_{PPPsp} = Max[0; i^{\max}]$ and $\hat{e}_{PPPsp} = Max[0; e^{\max}]$ will be achieved, which is identical to the result of the Hart (2003) model with linear utility functions.[61]■

7.4.2.2. Case P2 – The public authority's net payoffs are lower than the contractor's in a PPP setting

The final case of the analysis presented here is the PPP case where the public authority's net payoffs are lower than the contractor's net payoffs, i.e. $V_{C_{UNB}} > V_{PA_{UNB}}$. Accordingly, the psychological effect of advantageous inequality ("sense of guilt") is relevant to the contractor at the point of decision so that the second term of equation (7.10.) is equal to zero. Hence, the contractor's utility function is:

$$U_{C_{PPP-SP},P2} = V_{C_{PPP}} - \beta * \{V_{C_{PPP}} - V_{PA_{PPP}}\}$$

Again, $V_{C_{PPP}}$ and $V_{PA_{PPP}}$ can be substituted with equations (7.8.) and (7.9.). Hence, the following form for the contractor's utility function results:

$$U_{C_{PPP-SP},P2} = P_0 - C_0 + \gamma * i + c * e - i - e - \beta * \{P_0 - C_0 + \gamma * i + c * e - i - e - B_0 - \omega * i + o * e + P_0\} \quad (7.22.)$$

with $V_{C_{PPP}} > V_{PA_{PPP}}$, i.e. $P_0 - C_0 + \gamma * i + c * e - i - e > B_0 + \omega * i - o * e - P_0$, which is equivalent to $2P_0 > B_0 + \omega * i - o * e + C_0 - \gamma * i - c * e + i + e$.

For the partial analysis required to analyze the total effects, equation (7.22.) is differentiated with respect to i and e, leading to:

[61] The numerical example in section 7.5. will include the case where $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$ in order to illustrate this particular scenario.

$$\frac{\partial U_{C_{PPP-SP},P2}}{\partial i} = \gamma - 1 - \beta * \{\gamma - 1 - \omega\}$$
$$\Leftrightarrow \frac{\partial U_{C_{PPP-SP},P2}}{\partial i} = \gamma - 1 + \beta * \{1 + \omega - \gamma\} \tag{7.23.}$$
$$\Leftrightarrow \frac{\partial U_{C_{PPP-SP},P2}}{\partial i} = (1-\beta) * \gamma - 1 + \beta * \{1 + \omega\}$$

and

$$\frac{\partial U_{C_{PPP-SP},P2}}{\partial e} = c - 1 - \beta * \{c - 1 + o\}$$
$$\Leftrightarrow \frac{\partial U_{C_{PPP-SP},P2}}{\partial e} = c - 1 + \beta * \{1 - c - o\} \tag{7.24.}$$
$$\Leftrightarrow \frac{\partial U_{C_{PPP-SP},P2}}{\partial e} = (1-\beta) * c - 1 + \beta * \{1 - o\}$$

Hypothesis P2:

In the PPP case when psychological effects from disadvantageous inequality apply, several optimal investment combinations can result, depending on the productivity parameters, γ, ω, o *and* c*. Assuming that the parameters are such that they reproduce the results of the Hart (2003) model, the possible optima include the combinations* $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} = 0)$ *(with the first-best combination also being possible) and* $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$.

Argument P2:

As in the case P1, the parameters are consistent with Hart's (2003) model so that the contractor's net payoffs increase with every productive and unproductive investment since $\gamma > 1$ and $c > 1$. Thus, from the perspective of his own net payoffs, the contractor has again an incentive to make the highest possible amount of productive and unproductive investments and it has to be analyzed how the psychological effect influences this incentive scheme.

From a partial perspective, the psychological effect of an investment in e will be negative in any case as $\beta * \{1 - c - o\} < 0$ for $c > 1$. In addition, it can be also seen that the increase in the net payoffs will not be high enough to cover the losses from the negative psychological effect in any case, i.e. $c-1+\beta*\{1-c-o\}<0$ for any parameter combination that respects the conditions $c>1$ and $c-o<1$. Thus, the contractor does not have an incentive to make unproductive investments from a partial perspective.

Regarding productive investments, the partial analysis needs further distinctions as the psychological effect from a productive investment can be either positive if $\beta*\{1+\omega-\gamma\}>0$ or negative if $\beta*\{1+\omega-\gamma\}<0$. When including the effects of a productive investment on the net payoffs into the partial analysis, it can be seen that the contractor will always have an incentive to make productive investments i since $\gamma-1+\beta*\{1+\omega-\gamma\}>0$ (which is equivalent to $\gamma-1>\beta*\{\gamma-1-\omega\}$) holds for any combination of parameters with $\gamma>1$, $\omega>0$, and $0\leq\beta<1$.

As the partial analysis revealed that the contractor will not have an incentive to make unproductive investments in any case and will always have an incentive to make productive investments when the parameters are consistent with the parameters of the Hart (2003) model, the optimal investment combinations $(\hat{\imath}_{PPPsp}=0;\hat{e}_{PPPsp}=0)$ and $(\hat{\imath}_{PPPsp}=0;\hat{e}_{PPPsp}>0)$ are not possible. $(\hat{\imath}_{PPPsp}=0;\hat{e}_{PPPsp}=0)$ cannot be realized as the partial analysis revealed that the contractor always has an incentive to invest $\hat{\imath}_{PPPsp}>0$, and $(\hat{\imath}_{PPPsp}=0;\hat{e}_{PPPsp}>0)$ cannot be realized as the necessary condition would be that the contractor has higher incentives to make unproductive investments than productive investments from a partial perspective, which is not possible as the partial incentive is $\hat{e}_{PPPsp}=0$. Thus, it has to be analyzed whether and under which conditions the combinations $(\hat{\imath}_{PPPsp}>0;\hat{e}_{PPPsp}=0)$ and $(\hat{\imath}_{PPPsp}>0;\hat{e}_{PPPsp}>0)$ are realizable.

a) As it is known from the partial analysis that the contractor has an incentive to make productive investments i for any combination of parameters consistent with the Hart (2003) model, the optimal combination of investments $(\hat{\imath}_{PPPsp}>0;\hat{e}_{PPPsp}=0)$ can be realized through two scenarios.

   In the first scenario, the psychological influence for both types of investments is effective in the same direction. Hence, if the psychological effect from an investment in i is negative, i.e. $\beta*\{1+\omega-\gamma\}<0$, and if the psychological effect from an investment in e is also negative, i.e., $\beta*\{1-c-o\}<0$, which is given for any combination of parameters with $c>1$, then the resulting optimal investment combination is $(\hat{\imath}_{PPPsp}>0;\hat{e}_{PPPsp}=0)$ in any case.

In the second scenario, the psychological influence of an investment in i is positive, and consequently is effective in the opposite direction of the psychological influence of an investment in e. Hence, the analysis has to focus on the differences in payoffs and the maximum amount of investments that are possible, i.e. $[0;e]$ and $[0;i]$. Here, the contractor will make productive investments i as long as $V_{PA_{PPP}} < V_{C_{PPP}}$. If the advantageous difference in payoffs in favor of the contractor is high enough that the contractor will invest $\hat{\imath}_{PPPsp} = Max[0;i^{\max}]$, then the optimal combination of investments $(\hat{\imath}_{PPPsp} > 0;\hat{e}_{PPPsp} = 0)$ *with* $\hat{\imath}_{PPPsp} = Max[0;i^{\max}]$*, i.e. the first-best, will be achieved.*

b) The optimal investment combination $(\hat{\imath}_{PPPsp} > 0;\hat{e}_{PPPsp} > 0)$ is closely tied to the just described scenario. Here, again, both psychological influences are effective in opposite directions. However, in this case, the contractor cannot invest $\hat{\imath}_{PPPsp} = Max[0;i^{\max}]$ as the difference in payoffs is not high enough. Hence, the contractor will make unproductive investments e in order to increase the differences in payoffs since he can in turn make more productive investments through this, so that the optimal combination of productive and unproductive investments will be $(\hat{\imath}_{PPPsp} > 0;\hat{e}_{PPPsp} > 0)$. As in case P1 (see section 7.4.2.1.), a combination with $\hat{\imath}_{PPPsp} = Max[0;i^{\max}]$ and $\hat{e}_{PPPsp} = Max[0;e^{\max}]$ can be achieved, which is identical to the result of the Hart (2003) model assuming linear utility functions.■

With the theoretical analysis of the contractor's investment incentives completed, the following tables summarize the results and compare the findings of the model presented in this essay with the results of the standard model of Hart (2003), and then the next section illustrates the theoretical findings with a numerical example. Again, it has to be emphasized that the results derived in the actual model were developed assuming that the parameters are consistent with the Hart (2003) model.

	Hart (2003) model (with linear functions)	Yildiz (2015) model $V_{C_{UNB}} < V_{PA_{UNB}}$	Yildiz (2015) model $V_{C_{UNB}} > V_{PA_{UNB}}$
Unbundling case	There exists only one optimal investment combination: $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} = 0)$	There exist several optimal combinations depending on the productivity parameters: a) $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} = 0)$ if $o < \frac{1}{\alpha} + (1 + c)$ b) $(\hat{\imath}_{Usp} = 0; \hat{e}_{Usp} > 0)$ if $o > \frac{1}{\alpha} + (1 + c)$	There exists only one optimal investment combination: $(\hat{\imath}_{Usp} > 0; \hat{e}_{Usp} = 0)$; with $\hat{\imath}_{Usp} = i^* = Max[0; i^{\max}]$ possible if P_0 high enough. This optimum is resulting, irrespective of the productivity parameters as long as the parameters are consistent with the Hart (2003) model.

Tab.7.1.: Summary of the model's results in the unbundling case and comparison with the Hart (2003) model.

(Author's design).

	Hart (2003) model (with linear functions)	Yildiz (2015) model $V_{C_{UNB}} < V_{PA_{UNB}}$	 $V_{C_{UNB}} > V_{PA_{UNB}}$
PPP case	There exists only one optimal investment combination: $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$ Note: If linear functions as in the Yildiz (2015) model are applied, then the optimal combination of investments is $(\hat{\imath}_{PPPsp} = Max[0; i^{\max}]; \hat{e}_{PPPsp} = Max[0; e^{\max}])$. The condition to realize this optimum is $\gamma > 1$ and $c > 1$. Otherwise, other optimal combinations in the PPP case of Hart (2003) model) can result.	There exist several optimal combinations depending on the productivity parameters: a) $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} = 0)$ if $\gamma > c + \frac{\alpha}{1+\alpha} * \{o + \omega\}$ $\hat{\imath}_{PPPsp} = i^* = Max[0; i^{\max}]$ possible b.1.) $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} > 0)$ if $c > \gamma + \frac{\alpha}{1+\alpha} * \{-\omega - o\}$ and $\alpha * \{\gamma - \omega - 1\} > 0$; with $e_{PPPsp} = Max[0; e^{\max}]$ possible b.2.) $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} > 0)$ if $c > \gamma + \frac{\alpha}{1+\alpha} * \{-\omega - o\}$ and $\alpha * \{\gamma - \omega - 1\} < 0$; and the contractor can invest $\hat{e}_{PPPsp} = Max[0; e^{\max}]$ c) $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$ if $c > \gamma + \frac{\alpha}{1+\alpha} * \{-\omega - o\}$ and $\alpha * \{\gamma - \omega - 1\} < 0$; and contractor has to invest $\hat{\imath}_{PPPsp} > 0$ in order to move toward $\hat{e}_{PPPsp} = Max[0; e^{\max}]$	There exist several optimal combinations depending on the productivity parameters: a.1.) $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} = 0)$ if $\beta * \{1 + \omega - \gamma\} < 0$ with $\hat{\imath}_{PPPsp} = i^* = Max[0; i^{\max}]$ possible a.2.) $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} = 0)$ if $\beta * \{1 + \omega - \gamma\} > 0$ and the contractor can invest $\hat{\imath}_{PPPsp} = i^* = Max[0; i^{\max}]$ b) $(\hat{\imath}_{PPPsp} > 0; \hat{e}_{PPPsp} > 0)$ if $\beta * \{1 + \omega - \gamma\} > 0$ and contractor has to invest $\hat{e}_{PPPsp} > 0$ in order to move toward $\hat{\imath}_{PPPsp} = Max[0; i^{\max}]$

Tab.7.2.: Summary of the model's results in the PPP case and comparison with the Hart (2003) model.
(Author's design).

7.5. Simulation of the contractor's behavior

In the following, a numerical example whose results are graphically visualized with the software Wolfram Mathematica displays the theoretical insights presented in the previous sections 7.4.1. and 7.4.2.

The numerical example starts with assigning values to the variables. The productivity parameters were chosen so that they replicate the results of the Hart (2003) model with linear functions. The values for the aversion parameters α and β were derived according to the Fehr and Schmidt (1999) model. Here, as also addressed in section 7.4.1.2., Fehr and Schmidt (1999) elaborated on the range of the aversion parameters and discussed interpretations of different values. Thus, $\beta > 0.5$ implies an economic agent who disposes of a sense of guilt and suffers from advantageous distributional inequality. Regarding α, it has to be stated that there is no upper bound on the sense of envy. In fact, assumptions about the distribution of preferences derived from the analysis of experimental results on the ultimatum game reveal that more than 40 per cent of the experiments' participants showed a behavior that corresponds to an α of higher than $\alpha \geq 1$ (Fehr and Schmidt 1999). According to this, the values of the variables are as follows:

$B_0 = 100$; $C_0 = 20$; $P_0 = 50$; $o(e) = e$; $c(e) = 1.5 * e$; $\gamma(i) = 1.5 * i$; $\omega(i) = i$; $\alpha = 1.5$; $\beta = 0.6$

When inserting these values into the net benefit function of the economic exchange (see equation 7.3.), the following function results:

$$\begin{aligned} & U_{Soc.}(e,i) = 100 + i - e - 20 + 1.5 * i * + 1.5 * e - i - e \\ \Leftrightarrow \quad & U_{Soc.}(e,i) = 80 + 1.5 * i - 0.5 * e \end{aligned}$$

Hence, it is clear that this function will be optimized when $i* = Max[0; i^{\max}]$ and $e* = 0$, which can be also seen in Figure 7.2. (**Fig. 7.2.**).

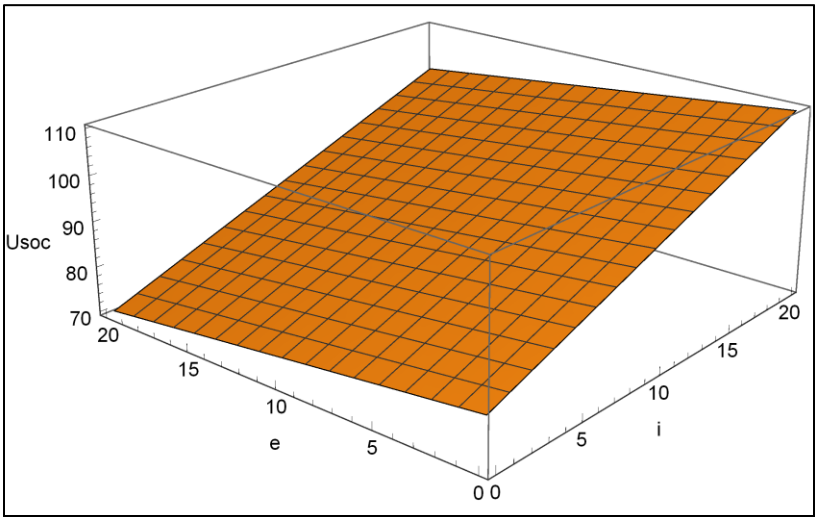

Fig. 7.2.: 3D plot of the society's net utility function.
(Author's design, made with Wolfram Mathematica).

Figure 7.2. (**Fig. 7.2.**) shows in a 3D plot the society's utility function (equation (7.3.)) with the above defined values for the model's variables and for the interval $i \in [0;20]$ and $e \in [0;20]$. As predicted, the society's net utility is maximized (i.e., graphically the highest point of the plot) where $i^* = 20$ (i.e., $i^* = Max[0; i^{\max}]$) and $e^* = 0$.

With this first-best solution for the investment in mind, the following section will analyze the contractor's investment incentives given preferences for distributional fairness in the respective cases, starting with the unbundling case.

7.5.1. The unbundling case

Applying the numerical example to equations (7.4.) and (7.6.), we obtain the following results for the involved parties' net payoffs:

$$V_{C_{UNB}} = 50 - i - e \tag{7.25.}$$

$$V_{PA_{UNB}} = 30 + 2.5 * i + 0.5 * e \tag{7.26.}$$

The contractor's objective is to maximize his utility, which is in the standard model equal to his payoffs $V_{C_{UNB}}$. Hence, it is consequential that a utility maximizing contractor will not invest neither in i nor in e, i.e., $\hat{i} = 0$ and $\hat{e} = 0$, as we can see from equation (7.25.) that any further investment will reduce the contractor's payoffs. This result can also be shown graphically (**Fig.7.3.**). Here, the highest point of the plane is at the combination of $\hat{i} = 0$ and $\hat{e} = 0$.

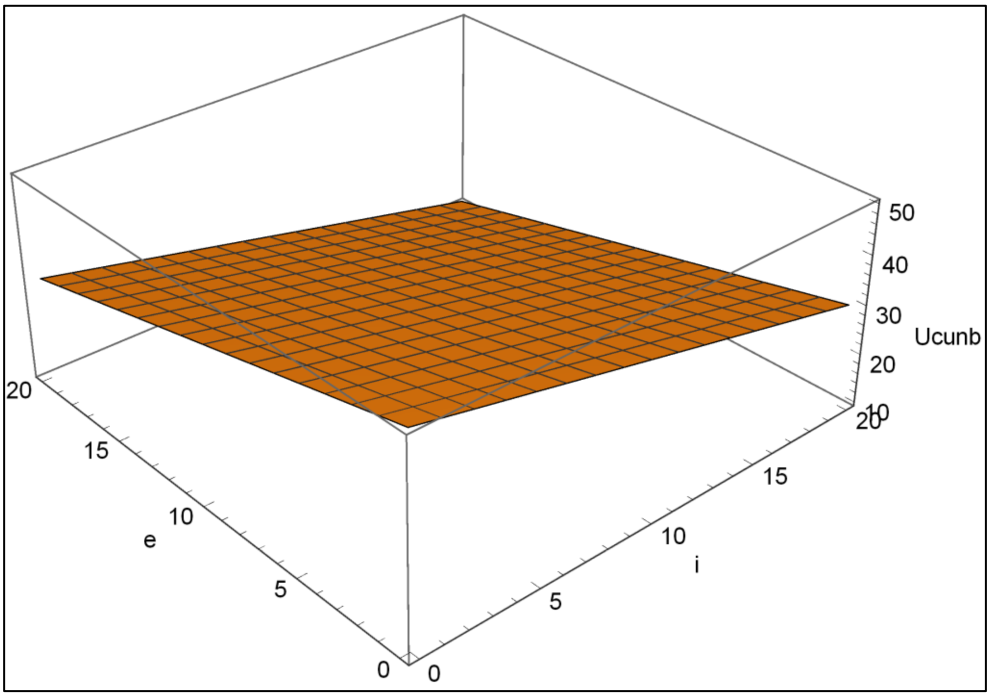

Fig. 7.3.: 3D plot of the contractor's utility in the unbundling case in the standard model. (Author's design, made with Wolfram Mathematica).

Assuming that the contractor has preferences for distributional equality, his investment incentives change significantly.

When applying the numerical example to equation (7.7.), the contractor's utility function with preferences for distributional equality is as follows:

$$U_{C_{UNB-SP}} = 50 - i - e - 1.5 * max\{-20 + 3.5 * i + 1.5 * e, 0\} - 0.6 * max\{20 - 3.5 * i - 1.5 * e, 0\} \quad (7.27.)$$

From the terms in the brackets, it can be seen that for the numerical example above, the psychological effect from advantageous inequality applies at the point of decision as the term in the brackets of the second term (i.e., $-20 + 3.5 * i + 1.5 * e$), representing the psychological effect of envy, is below zero for the values of $i = 0$ and $e = 0$. In other words, the term in the brackets of the second term, i.e. $V_{PA_{UNB}} - V_{C_{UNB}}$, is below zero for the values of $i = 0$ and $e = 0$. Hence, the condition $V_{PA_{UNB}} < V_{C_{UNB}}$ applies, meaning that the contractor suffers from the psychological effect of advantageous inequality as long as $V_{PA_{UNB}} < V_{C_{UNB}}$ holds. Figure 7.4. (**Fig.7.4.**) will show the depiction of the contractor's utility for the above defined numerical example from two different angles.

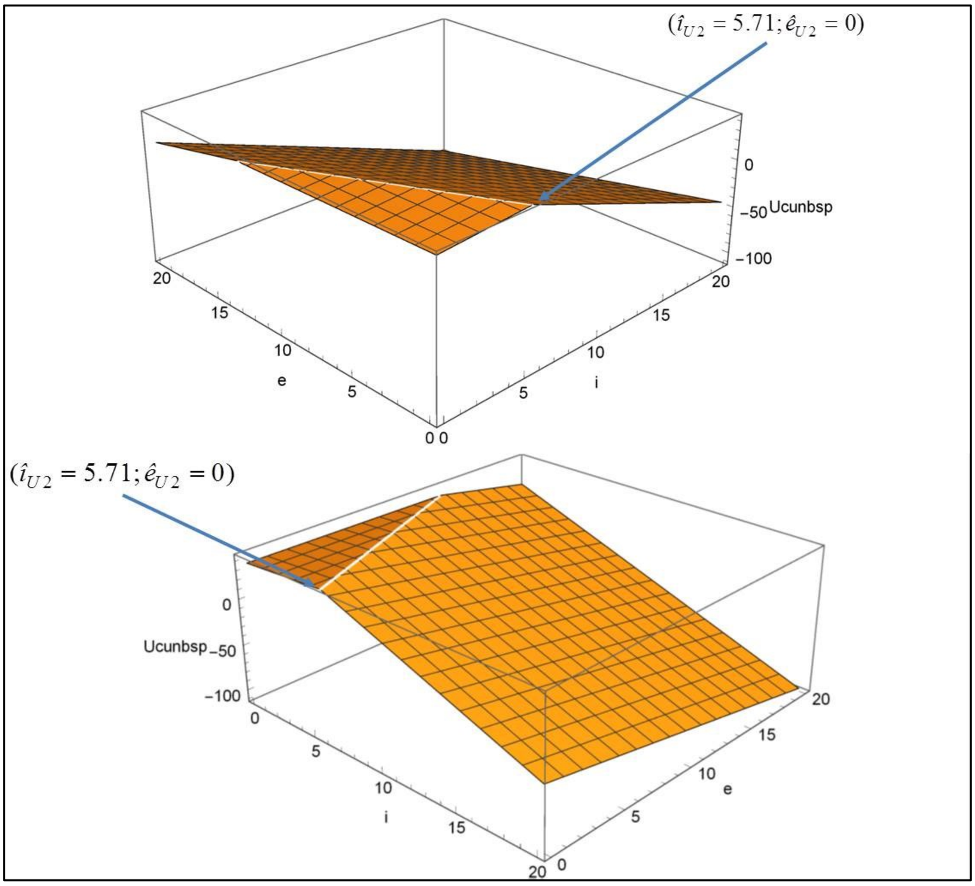

Fig.7.4.: 3D plot of the contractor's utility in the unbundling case when a sense of guilt applies. (Author's design, made with Wolfram Mathematica).

From **Fig.7.4.**, we see that, compared to the standard model, the applying sense of guilt induces investment incentives to the contractor. From equation (7.27.), we see that any investment in i will reduce advantageous inequality in payoffs, which raises the contractor's utility $U_{C_{UNB-SP}}$. As the positive effect on the contractor's utility from a reduction of advantageous inequality is higher than the loss of utility from the reduction in net payoffs, the contractor has incentives to make productive investments i as long as the psychological effect from a sense of guilt applies. In addition, we also see that any investment in e will likewise reduce advantageous inequality in payoffs, which raises the contractor's utility as long as the sense of guilt is relevant. However, regarding unproductive investments e, the positive effect on the contractor's utility from a reduction in advantageous inequality is lower than the loss of utility from the reduction in net payoffs. Hence, any investment in e lowers in total the contractor's utility $U_{C_{UNB-SP}}$.

From this assessment, we know that the optimal combination of investments to maximize the contractor's utility can only be at the point where the maximal amount of productive investments i is made before the vertex of the plane (i.e., the contractor's utility $U_{C_{UNB-SP}}$), i.e., $V_{C_{UNB}} = V_{PA_{UNB}}$, is reached. Hence, the optimal combination is $(\hat{\imath}_{Usp} = 5.71; \hat{e}_{Usp} = 0)$, which implies more productive investments than in the optimum of the standard model $(\hat{\imath} = 0; \hat{e} = 0)$. At the given combination of investment, we reach the vertex of the plane in **Fig.7.4.** This vertex represents the combination of investments i and e where the applying psychological effect is zero and afterwards changes from a sense of guilt to a sense of envy. When the applying effect changes, the negative psychological effect on the contractor's utility is intensified for any investment so that his utility will decrease. To summarize, the applying psychological effect of advantageous distributional inequality changed the contractor's incentives significantly as the optimal combination of investments now includes productive investments.[62]

As discussed in the theoretical assessment, a variation of the fixed payment P_0 to the contractor influences the optimal combination of investments as the payment P_0 determines how long a psychological effect persists. Figure 7.5. (**Fig. 7.5.**) will show the development of the contractor's utility when the payment P_0 is varied.

[62] The analysis on the planes (and therefore on the contractor's utility) run is only relevant for the above given numerical example. As elaborated in section 7.4.1., other parameter combinations can lead to scenarios where other investment combinations are optimal for the contractor.

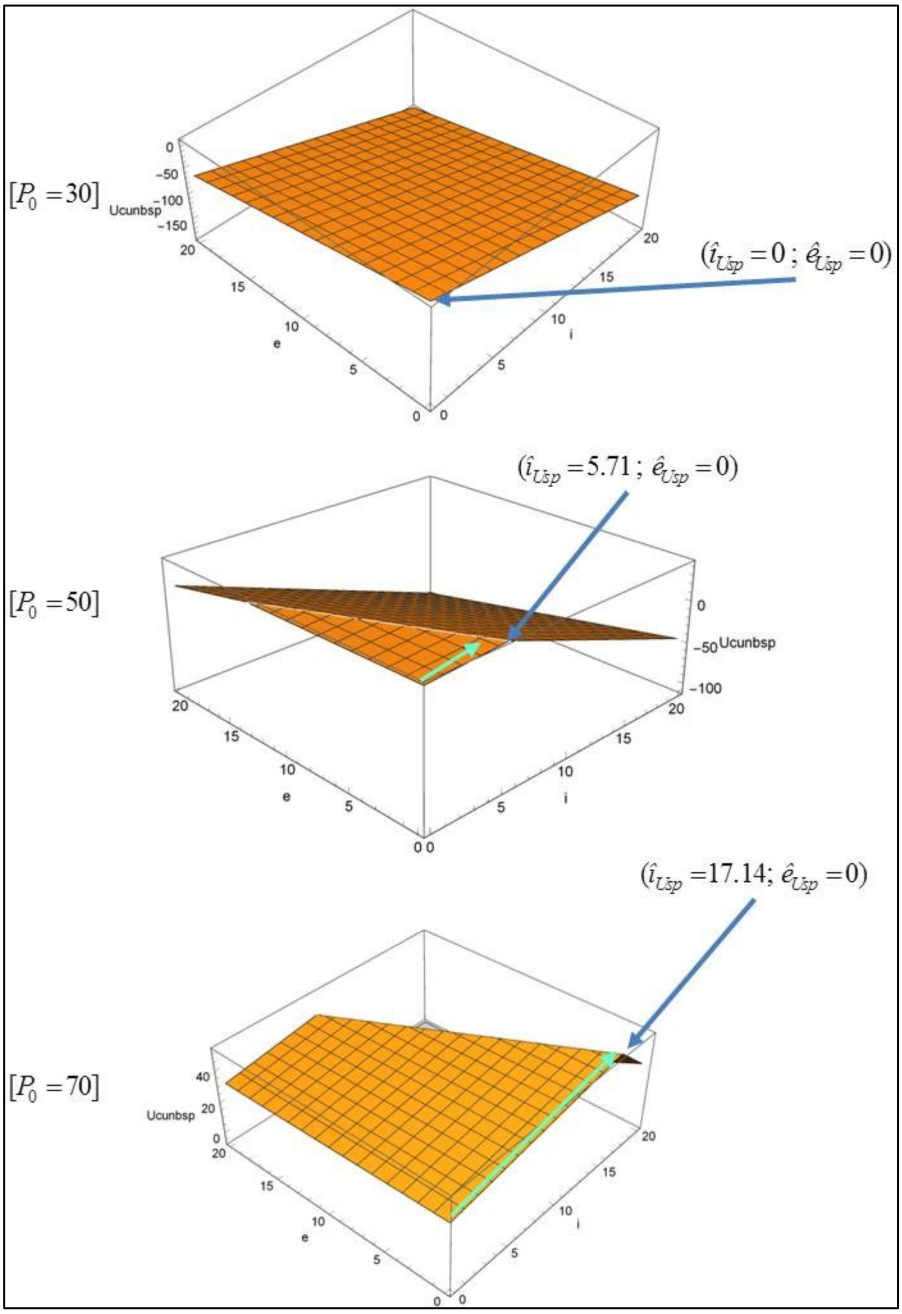

Fig.7.5.: 3D plot of the evolution of the contractor's utility in the unbundling case when P_0 is varied. (Author's design, made with Wolfram Mathematica).

In the first (upper) illustration of **Fig.7.5.**, the contractor's utility is illustrated when the payment P_0 for his service is $P_0 = 30$. Given this payment and all other parameters being the same as in the numerical example at the introduction of this subsection, his utility function changes to:

$$U_{C_{UNB-SP}} = 30 - i - e - 1.5 * max\{20 + 3.5 * i + 1.5 * e, 0\} - 0.6 * max\{-20 - 3.5 * i - 1.5 * e, 0\}$$

Here, it can be seen that the psychological effect from disadvantageous distributional inequality applies and that any productive or unproductive investment will reduce the contractor's utility. Hence, the optimal combination of investments is $(\hat{\imath}_{Usp} = 0\ ;\ \hat{e}_{Usp} = 0)$.

In the second (central) illustration of **Fig.7.5.**, the contractor's utility is illustrated when the payment P_0 for his service is $P_0 = 50$. This case has already been discussed and the result was that the optimal combination is $(\hat{\imath}_{Usp} = 5.71; \hat{e}_{Usp} = 0)$. The light blue arrow shows how the optimal combination is shifted compared to the initial case ($P_0 = 30$) as the psychological effects from a sense of guilt now apply. This incentivizes the contractor to make productive investments i as long as the sense of guilt applies.

In the third (lower) illustration of **Fig.7.5.**, the run of the contractor's utility is illustrated when the payment P_0 for his service is $P_0 = 70$. Here, his utility function changes to:

$$U_{C_{UNB-SP}} = 70 - i - e - 1.5 * max\{-60 + 3.5 * i + 1.5 * e, 0\} - 0.6 * max\{60 - 3.5 * i - 1.5 * e, 0\}$$

From the function term, it can be seen that the psychological effect from advantageous distributional inequality applies as in the previous case where $P_0 = 50$. However, for $P_0 = 70$, the distributional inequality is larger so that the contractor has a wider range to make productive and unproductive investments. As all other parameters of the numerical example are modified, the same rationale as for $P_0 = 50$ is applied. Hence, in the optimum, the contractor will not make unproductive investments and will invest as much as he can in productive investments i as long as the sense of guilt is effective (i.e. as long as $V_{PA_{UNB}} < V_{C_{UNB}}$). Accordingly, the optimal combination of investments is $(\hat{\imath}_{Usp} = 17.14; \hat{e}_{Usp} = 0)$. The light blue arrow in the lower illustration shows again the shift from the original optimum (where $P_0 = 30$).

7.5.2. The PPP case

The basis for the upcoming analysis is again the involved parties' payoffs. Accordingly, through applying the numerical example to equations (7.8.) and (7.9.), we obtain the following results for the respective net payoffs:

$$V_{C_{PPP}} = 30 + 0.5 * i + 0.5 * e \qquad (7.28.)$$

$$V_{PA_{PPP}} = 50 + i - e \qquad (7.29.)$$

Again, the contractor's objective is to maximize his utility. Hence, in the standard model, the contractor's utility is equal to his payoffs $V_{C_{PPP}}$. From equation (7.29.), we see that any investment in i and e will raise the contractor's payoffs so that a utility maximizing contractor will choose $\hat{\imath}_{PPP} = i^* = Max[0; i^{\max}]$ and $\hat{e}_{PPP} = Max[0; e^{\max}]$, which implies an overinvestment in unproductive investments e. Consequently, when plotting the contractor's utility for the interval $i \in [0;50]$ and $e \in [0;50]$, the combination of optimal investments in the PPP case will be $(\hat{\imath}_{PPP} = 50; \hat{e}_{PPP} = 50)$, as can be seen in figure 7.6. (**Fig.7.6.**).

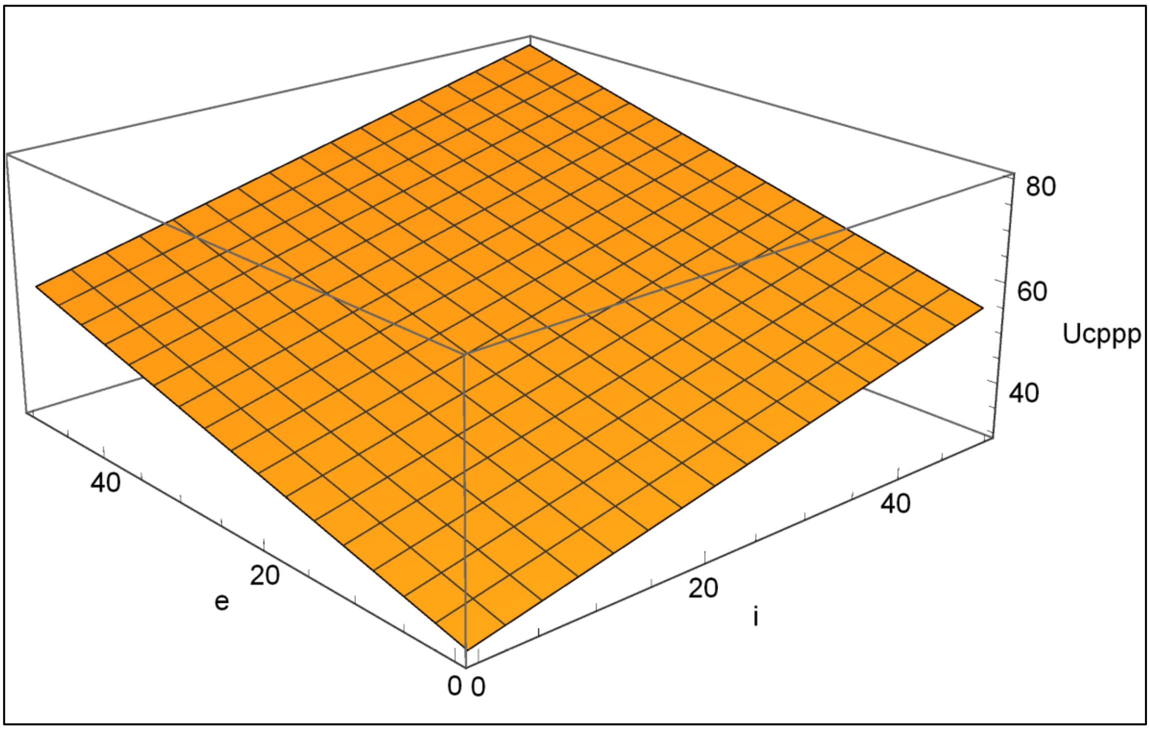

Fig. 7.6.: 3D plot of the contractor's utility in the PPP case in the standard model.
(Author's design, made with Wolfram Mathematica).

In analogy to the unbundling case, the contractor's investment incentives change significantly when he has preferences for a fair distribution of payoffs. Hence, applying the numerical example to equation (7.10.) delivers the following utility function for the contractor:

$$U_{C_{PPP-SP}} = 30 + 0.5*i + 0.5*e - 1.5*\max\{20 + 0.5*i - 1.5*e, 0\} - 0.6*\max\{-20 - 0.5*i + 1.5*e, 0\} \tag{7.30.}$$

Accordingly, we see from the utility function that a sense of envy will affect the contractor's utility at the point of decision as the term in the first bracket of the utility function $U_{C_{PPP-SP}}$, i.e., $\{20+0.5*i+1.5*e,0\}$, is positive for the starting values of the simulation, i.e., $i=0$ and $e=0$. The rationale underlying to this result is similar to the explanations in section 7.4.2.2. Figure 7.7. (**Fig.7.7.**) displays the contractor's utility in the PPP case for the above defined numerical example when fairness preferences are effective.

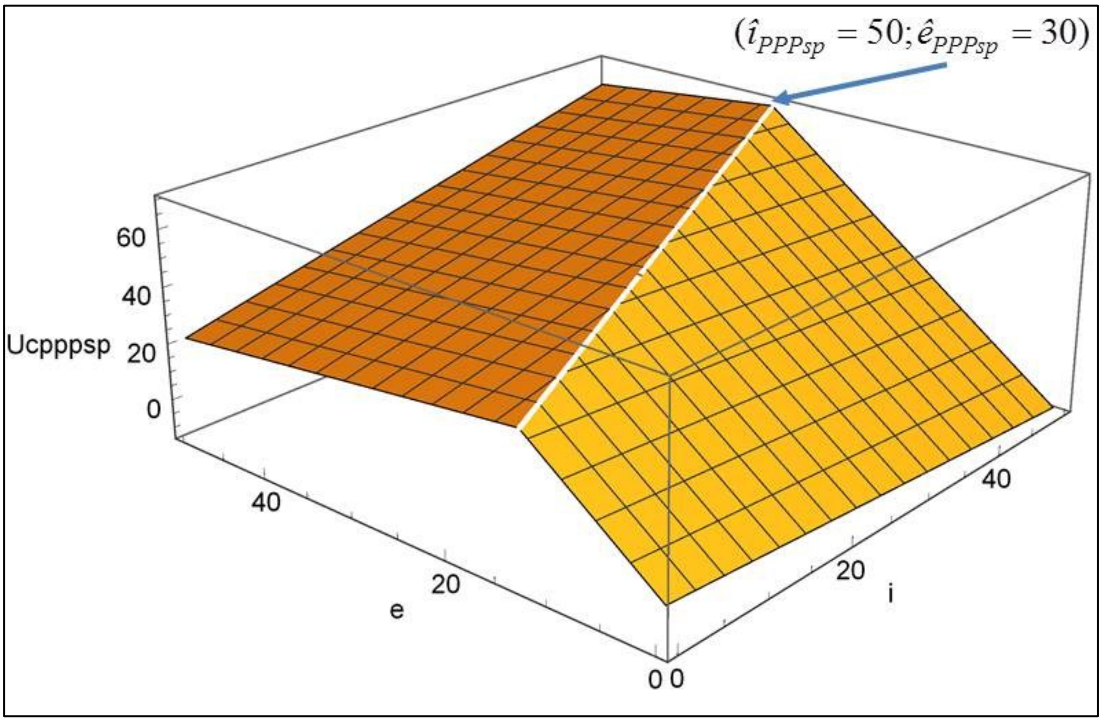

Fig.7.7.: 3D plot of the contractor's utility in the PPP case when a sense of envy applies.
(Author's design, made with Wolfram Mathematica).

As can be seen in **Fig.7.7.,** the optimal investment is $(\hat{\imath}_{PPPsp}=50;\hat{e}_{PPPsp}=30)$. This can be explained as any investment in e will raise the contractor's net payoffs as well as reduce the disadvantageous distributional inequality as the contractor now operates the infrastructure and profits from the cost reduction (as the relevant productivity parameter is $c>1$), whereas the public authority's net payoffs are reduced (as $-o*e=-e<0$). Hence, it is optimal for the contractor to invest as much as possible in unproductive investments. Without any investment in i, this amount would be $\hat{e}_{PPPsp}=13.\overline{3}$.

The examination of the partial effects of an investment in i reveals that a unit of productive investment i has a positive effect on the contractor's net payoffs (as we also

know from the standard model), but from equation (7.30.) we also see that an investment in i increases the disadvantageous inequality and consequently intensifies the negative psychological effect. As this negative effect on the contractor's utility is higher than the positive effect on the contractor's utility stemming from the increase in net payoffs that arise from an investment in i, the contractor would not have an incentive to make productive investments if it was based on a partial decision without any consideration of unproductive investments.
However, from an overall perspective including both types of investments simultaneously, the contractor has substantial incentives to make productive investments. The rationale is that any productive investment i allows the contractor to make more unproductive investments e. As the overall effect from an investment in unproductive investments e on the contractor's utility is higher than the effect of a productive investment, he chooses the combination where he can invest the most in unproductive investment e, i.e., $(\hat{\imath}_{PPPsp} = 50; \hat{e}_{PPPsp} = 30)$. Higher investments in unproductive investments in e are suboptimal as here, effects from advantageous inequality would apply where investments in e lower the contractor's utility (see equation 7.30.).
Similar to the numerical illustration of the unbundling case, a step-by-step variation of the fixed payment to the contractor P_0 also leads to an adjustment of the optimum as can be seen in figure 7.8. (**Fig.7.8.**).

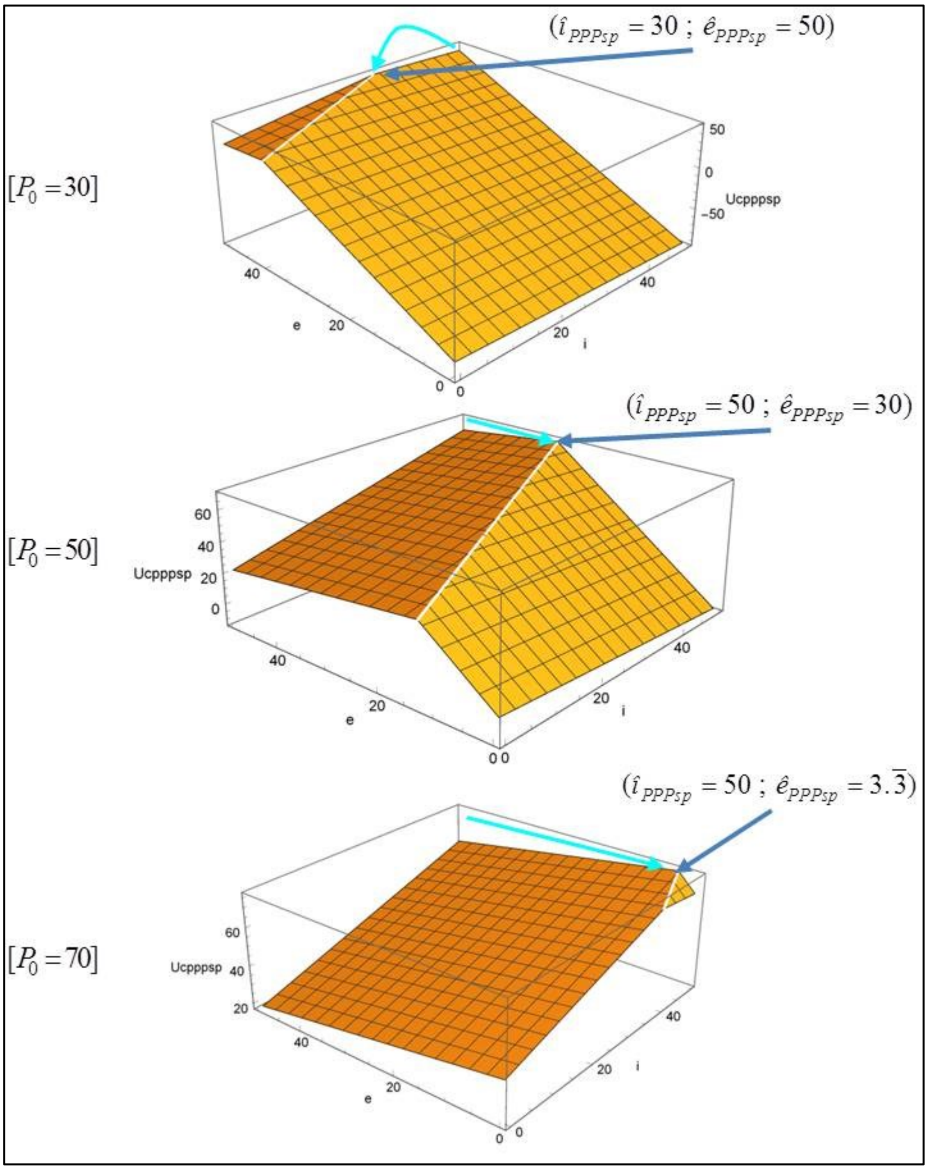

Fig.7.8.: 3D plot of the evolution of the contractor's utility in the PPP case when P_0 is varied. (Author's design, made with Wolfram Mathematica).

In the first (upper) illustration of **Fig.7.8.**, the contractor's utility in the PPP case is illustrated when the payment P_0 for his service is $P_0 = 30$. Given this payment and all other parameters being the same to the numerical example at the introduction of this subsection, his utility function changes to:

$$U_{C_{PPP-SP}} = 10 + 0.5 * i + 0.5 * e - 1.5 * \max\{60 + 0.5 * i - 1.5 * e, 0\} - 0.6 * \max\{-60 - 0.5 * i + 1.5 * e, 0\}$$

Here, it can be seen that the psychological effect from disadvantageous distributional inequality applies at the point of decision and that the contractor has an incentive to invest in unproductive investments e from the net payoff and psychological perspective. When making only unproductive investments, the contractor could invest $(\hat{\imath}_{PPPsp} = 0; \hat{e}_{PPPsp} = 40)$. However, through making productive investments in parallel, the contractor can “move” upwards on the vertex (where $V_{C_{PPP}} = V_{PA_{PPP}}$) of the plane and reach the combination of investments that maximizes his utility. Hence, the optimal investment combination when the payment to the contractor is $P_0 = 30$ is $(\hat{\imath}_{PPPsp} = 30; \hat{e}_{PPPsp} = 50)$. The light blue arrow in the upper illustration shows how the optimum is shifted compared to the standard model.

The second (central) illustration of **Fig.7.8.** shows the already discussed case of the contractor’s utility when the payment P_0 for his service is $P_0 = 50$. Here still, the sense of envy applies but the differences in net payoffs between both parties are lower than in the upper illustration so that the contractor makes more productive investments in order to invest the highest possible amount in unproductive investments. Hence, the optimal investment combination is at $(\hat{\imath}_{PPPsp} = 50; \hat{e}_{PPPsp} = 30)$.

In the third (lower) illustration of **Fig.7.8.** the run of the contractor’s utility is shown when the payment P_0 for his service is $P_0 = 70$. Here, his utility function changes to:

$$U_{C_{PPP-SP}} = 50 + 0.5*i + 0.5*e - 1.5*\max\{-20 + 0.5*i - 1.5*e, 0\} - 0.6*\max\{20 - 0.5*i + 1.5*e, 0\}$$

From the function term, it can be seen that the psychological effect from advantageous distributional inequality now applies at the point of decision. As we know from the analysis in section (7.4.2.2.), the contractor will try to make as many productive investments as possible. Furthermore, as the psychological influence of productive and unproductive investments are effective in opposite directions, the contractor might consider making unproductive investments in order to increase the highest possible amount of productive investments. If the contractor were only to make productive investments, then the resulting combination before the vertex of the plane is surpassed would be at $(\hat{\imath}_{PPPsp} = 40; \hat{e}_{PPPsp} = 0)$. However, by investing a small amount in e, the contractor can make more productive investments so that he arrives at the optimal combination of $(\hat{\imath}_{PPPsp} = 50 ; \hat{e}_{PPPsp} = 3.\overline{3})$ for this case. The light blue arrow shows again how the optimum is shifted compared to the standard model. Furthermore, the total of **Fig. 7.8.** illustrates the evolution of the optimum by only varying the fixed payment to the contractor P_0.

This last example concludes the analysis of the implications of ownership and social preferences in a PPP setting with incomplete contracts. The following section will discuss the findings of the model presented here in the light of previous findings, particularly the Hart (2003) model, and add some concluding remarks.

7.6. Discussion and Conclusion

The analysis presented here provided new insights into the investment behavior of economic agents in a PPP setting with contractual incompleteness and social preferences, some of them being fundamentally different from previous insights from incomplete contract theory.

First of all, the analysis revealed that if the contractor in a PPP setting disposes of preferences for distributional equality, not only the distribution of ownership rights has an influence on the contractor's investment incentives but also payments. This is due to the influence the fixed payment – that is, the price for providing the service – has on whether the contractor feels a sense of envy or a sense of guilt. Consequently, the public authority can set investment incentives for productive investments in the unbundling case as well as in the PPP case. This finding is substantially different from the incomplete contract literature in general based on standard (neoclassical) theory in which only the distribution of ownership rights has an influence on an economic agent's investment incentives (e.g. Hart 1995).

The implications of these findings are that by appealing to fairness (e.g. through a "gentlemen's agreement") and ensuring that the contractor is better off, the public authority can induce investment effects in either case, unbundling and PPP. Hence, it is important for the public authority to ensure that it has enough funds to make payment for the contractor's construction service that makes him better off. In addition, the public authority (or the commanding party in general) can further influence the invested amount by varying its payments. Hence, if the public authority has complete information on the contractor's preferences and productivity parameters, it can choose an ownership form and make a payment so that the socially optimum first-best is reached, that is, the contractor invests the maximum amount of productive investments i without any unproductive investments e.

On the contrary, if the public authority can foresee that it will not be able to pay a price that favors the contractor, a scenario can be realized in which the contractor only makes unproductive investments without any productive investments. This implies that an envious contractor might use unproductive investments as a measure to regulate “unfair” payments from the public authority. This behavior can also be observed in other contexts such as the provision of public goods or international climate negotiations. Here, parties might have a lower incentive for unilateral mitigation efforts when they feel they are being exploited by free-riders (e.g. Buchholz et al. 2014; Bolle et al. 2015).

When discussing these insights and the recommendations for action, it has to be considered that the model presented here is very simple and the results and recommendations are drawn through a casuistic approach. Nonetheless, the model helps to present a first impression of possible effects from social preferences in an incomplete contract setting.

In order to provide further insight on the behavior of economic agents in a decentralized investment scenario, further research could seek to simulate a PPP scenario and compare whether the observations in experiments are consistent with the theoretical predictions. In addition, these experiments could also serve to assess the aversion parameters. Analogous to Fehr and Schmidt (1999), the distribution of preferences could be analyzed according to the experimental results. This assessment in turn could be used in order to further develop the theoretical framework for the analyzed setting.

7.7. Literature

Alanne, K./ Saari, A. (2006). Distributed energy generation and sustainable development. In: *Renewable and Sustainable Energy Reviews*, 10 (6), 539-558.

Alchian, A.A./ Demsetz, H. (1972): Production, information costs, and economic organization. In: *The American Economic Review*, 62 (5), 777-795.

Becker, S./ Beveridge, R./ Naumann, M. (2015): Remunicipalization in German cities: contesting neo-liberalism and reimagining urban governance?. In: Space and Polity, 19 (1), 76-90.

Besley, T.J./ Ghatak, M. (2001): Government versus private ownership of public goods. In: The Quarterly Journal of Economics, 116 (4), 1343-1372

Binmore, K.G./ Shaked, A./ Sutton, J. (1985): Testing Noncooperative Bargaining Theory: A Preliminary Study. In: *The American Economic Review*, 75 (5), 1178-1180.

Bolle, F./ Buchholz, W./ Peters, W./ Schwarze, R./ Ufert, A./ Gneuss, P./ Yildiz, Ö. (2015): *Reciprocity and Trust as Factors for Success in International Climate Policy*. Discussion Paper Series recap15 No 19 (English), Europa- Universität Viadrina, Frankfurt (Oder), Germany, 2015.

Bowles, S.S. (1998): Endogenous Preferences: The Cultural Consequences of Markets and other Economic Institutions. In: *Journal of Economic Literature*, 36 (1), 75-111.

Buchanan, J.M. (1984): *Politics without romance: A sketch of positive public choice theory and its normative implications*. In: Buchanan, J.M./ Tollison, R.D. [eds.]: The theory of public choice II. The University of Michigan Press, Ann Arbor, MI, 1984, pp. 11-22.

Buchholz, W./ Peters, W./ Ufert, A. (2014): Spielräume für uni- und multilateralen Klimaschutz. In: *Zeitschrift für Umweltpolitik & Umweltrecht*, 37 (3), 326-344.

Camerer, C.F./ Loewenstein, G.F. (2004): Behavioral Economics: Past, Present, Future. In: Camerer, C.F./ Loewenstein, G.F./ Rabin, M. [eds.]: Advances in Behavioral Economics. Princeton University Press (i.a.), Princeton, NJ (i.a.), 2004, pp. 3-52.

Chalkley, M./ Malcomson, J.M. (1998): Contracting for health services when patient demand does not reflect quality. In: *Journal of Health Economics*, 17 (1), 1-19.

Coase, R.H. (1937): The nature of the firm. In: *Economica*, 4 (16), 386-405.

Coase, R.H. (1960): The Problem of social cost. In: *Journal of Law & Economics*, 3 (1), 1-44.

Devine-Wright, P. (2005): Local aspects of UK renewable energy development: exploring public beliefs and policy implications. In: *Local Environment*, 10 (1), 57-69.

Fehr, E./ Schmidt, K. M. (1999): A theory of fairness, competition, and cooperation. In *The Quarterly Journal of Economics*, 114 (3), 817-868.

Fehr, E./ Schmidt, K.M. (2006): The Economics of Fairness, Reciprocity and Altruism – Experimental Evidence and New Theories. In: Kolm, S.-C./ Mercier Ythier, J. [eds.]: Handbook of the Economics of Giving, Altruism and Reciprocity – Volume 1. North Holland (i.a.), Amsterdam (i.a.), 2006, pp. 615-691.

Fehr, E./ Kremhelmer, S./ Schmidt, K. M. (2008): Fairness and the Optimal Allocation of Ownership Rights. In: *The Economic Journal*, 118 (531), 1262-1284.

Foxon, T.J./ Hammond, G.P./ Pearson, P.J. (2010): Developing transition pathways for a low carbon electricity system in the UK. In: *Technological Forecasting and Social Change*, 77 (8), 1203-1213.

Francesconi, M./ Muthoo, A. (2006): *Control rights in public-private partnerships*. CEPR Discussion Paper No. 5733, Centre for Economic Policy Research (CEPR), London, UK, 2006.

Grossman, S.J./ Hart, O.D. (1986): The costs and benefits of ownership: A theory of vertical and lateral integration. In: *The Journal of Political Economy*, 94 (4), 691-719.

Güth, W./ Schmittberger, R./ Schwarze, B. (1982): An experimental Analysis of Ultimatum Bargaining. In: *Journal of Economic Behavior & Organization*, 3 (4), 367-388.

Hall, D./ Lobina, E./ Terhorst, P. (2013): Re-municipalisation in the early twenty-first century: water in France and energy in Germany. In: *International Review of Applied Economics*, 27 (2), 193-214.

Hart, O. (1995): *Firms, Contracts, and Financial Structure*. Clarendon Press/ Oxford University Press, New York, NY, 1995.

Hart, O. (2003): Incomplete contracts and public ownership: Remarks, and an application to public-private partnerships. In: *The Economic Journal*, 113 (486), C69-C76.

Hart, O./ Moore, J. (1990): Property Rights and the Nature of the Firm. In: *Journal of Political Economy*, 98 (6), 1119-1158.

Hart, O./ Shleifer, A./ Vishny, R.W. (1997): The proper scope of government: theory and an application to prisons. In: *The Quarterly Journal of Economics*, 112 (4), 1126-1161.

Höfer, H.H./ Rommel, J. (2015): Internal governance and member investment behavior in energy cooperatives: An experimental approach. In: *Utilities Policy*, 36, 52-56.

Jensen, M.C./ Meckling, W.H. (1976): Theory of the firm: Managerial behavior, agency costs and ownership structure. In: *Journal of Financial Economics*, 3 (4), 305-360.

Karger, C.R./ Hennings, W. (2009): Sustainability evaluation of decentralized electricity generation. In: *Renewable and Sustainable Energy Reviews*, 13 (3), 583-593.

Khalil, E.L. (2004): What is altruism?. In: *Journal of Economic Psychology*,25 (1), 97-123.

Laffont, J.J./ Tirole, J. (1991): Privatization and incentives. In: *Journal of Law, Economics, & Organization*, 7, 84-105.

Martins, A.C./ Marques, R. C./ Cruz, C. O. (2011): Public-private partnerships for wind power generation: the Portuguese case. In: *Energy Policy*, 39 (1), 94-104.

Meadowcroft, J. (2009): What about the politics? Sustainable development, transition management, and long term energy transitions. In: *Policy Sciences*, 42 (4), 323-340.

Monstadt, J. (2007): Urban governance and the transition of energy systems: Institutional change and shifting energy and climate policies in Berlin. In: *International Journal of Urban and Regional Research*, 31 (2), 326-343.

Pepermans, G./ Driesen, J./ Haeseldonckx, D./ Belmans, R./ D'haeseleer, W. (2005): Distributed generation: definition, benefits and issues. In: *Energy policy*, 33 (6), 787-798.

Rabin, M.J. (1993): Incorporating Fairness into Game Theory and Economics. In: *The American Economic Review*, 83 (5), 1281-1302.

Roth, A.E./ Malouf, M.W.K./ Murnighan, J.K. (1981): Sociological versus strategic factors in bargaining. In: *Journal of Economic Behavior & Organization*, 2 (2), 153-177.

Saussier, S./ Staropoli, C./ Yvrande-Billon, A. (2009): Public–Private Agreements, Institutions, and Competition: When Economic Theory Meets Facts. In: *Review of Industrial Organization*, 35 (1-2), 1-18.

Schmidt, K.M. (1996): The costs and benefits of privatization: an incomplete contracts approach. In: *Journal of Law, Economics, and Organization*, 12 (1), 1-24.

Schmitz, P.W. (2001): The hold-up problem and incomplete contracts: a survey of recent topics in contract theory. In: Bulletin of Economic Research, 53 (1), 1-17.

Schönfeld, F. (2011): Optimales Investitionsverhalten und Verfügungsrechte in Public Private Partnerships. Nomos Verlag, Baden-Baden, Germany 2011.

Shleifer, A. (1998): State versus private ownership. In: *Journal of Economic Perspectives*, 12 (4), 133-150.

Simon, H.A. (1998): *Psychology and Economics*. In: Davis, J.B./ Hands, D.W/. Mäki, U. [eds.]: The Handbook of Economic Methodology. Edward Elgar Publishing, Cheltenham (i.a.), UK, 1998, pp. 393-397.

Smith, A./ Stirling, A./ Berkhout, F. (2005): The governance of sustainable socio-technical transitions. In: *Research Policy*, 34 (10), 1491-1510.

Sovacool, B.K. (2013): Expanding renewable energy access with pro-poor public private partnerships in the developing world. In: *Energy Strategy Reviews*, 1 (3), 181-192.

Schweizer, U. (1988): Externalities and the Coase theorem: Hypothesis or result?. In: *Journal of Institutional and Theoretical Economics (JITE)/ Zeitschrift für die gesamte Staatswissenschaft*, 144 (2), 245-266.

Yildiz, Ö. (2014): Financing renewable energy infrastructures via financial citizen participation – The case of Germany. In: *Renewable Energy*, 68, 677-685.

Williamson, O. E. (1975): *Markets and hierarchies: antitrust analysis and implications*. The Free Press, New York, NY, 1975.

Chapter 8: General Summary and Outlook[63]

When reviewing the previous chapters, various findings can be drawn from the separate analyses of the essays on their own as well as from the analysis of the thesis as a whole. Hence, this chapter will, in a first step, analyze the essays separately, then highlight the common denominator of this thesis, and finally discuss approaches for further research.

8.1. Summary of the essay's contributions from an individual perspective

The meta-analysis conducted in the first essay (Chapter 2: Financing renewable energy infrastructures via financial citizen participation – the case of Germany) particularly addressed the opening question from the list of guiding questions to this thesis (see section 1.2.). Hence, in search of important actors and other essential characteristics for the progress of the "Energiewende" in recent years, the first essay highlights the role of citizen investors and various business models involving private individuals. Furthermore, this essay also revealed a connection between the underlying technology and the suitability of a specific business model. To summarize, this essay has laid the groundwork for the following essays of this thesis as it carved out the significance of bottom-up approaches and citizen participation (in a narrower and broader sense) for the progress of the "Energiewende".

The findings of the first essay were followed by further research from other authors that among other things investigated the role of investing citizens, community energy, and decentralized energy infrastructures in other countries (Haggett and Aitken 2015; Romero-Rubio and de Andrés Díaz 2015), analyzed sociodemographic characteristics of involved citizens in the renewable energy sector (Fraune 2015), drew attention to internal governance aspects of specific business models (Höfer and Rommel 2015 for the case of energy cooperatives), and searched for strategies to intensify further the involvement of citizens as investors in the renewable energy sector through new business models (Vasileiadou et al. 2015).

The second essay (Chapter 3: Energy cooperatives in Germany – growth of energy cooperatives and an analysis from a new institutional economics perspective) is tied closely to the first essay, but focuses on a specific organizational form. Technically speaking, the second essay conducts a theoretical analysis of energy cooperatives

[63] The author would like to thank Dr. Ian Mcnaught, text editor at Cambridge Proofreading LLC (http://proofreading.org/), for the language-editing of this chapter.

by using the rationale of transaction cost economics. According to this, solar energy is particularly suited for the cooperative business model as the underlying technology and the value-added process are not prone to high transaction costs while the value-added process and heterogeneity of actors underlying the bioenergy infrastructures are characterized by a higher degree of specificity, so that a vertically integrated organizational form seems to be more suited from a transaction cost perspective. Hence, this essay contributes to the human–technology–institution nexus that is essential from a management perspective in the context of renewable energy (see second question in section 1.2.).

The third and fourth essays have to be examined together as both essays not only provide an answer to challenges from the managerial perspective (see second question in section 1.2.) but also show how transdisciplinary research methods can be included into research in the context of the "Energiewende" (see fourth question in section 1.2.).

Through a formal, microeconomic approach using a nested constant elasticity of substitution production function approach, the third essay (Chapter 4: A microeconomic analysis of decentralized small scale biomass based CHP plants – the case of Germany) develops a tool for the optimization of biogas plants and contributes through this to the topic of management questions in the context of renewable energy infrastructures. In addition, the aspect of transdisciplinarity is also related as actors from nonacademia can be involved in the process of data gathering and development of input factor scenarios. Furthermore, the numerical examples based on the tool can be extended to a dataset where standard combinations of input factors are tested with regard to optimality. These data can be consolidated with other comparable tools to provide a standardized instrument for project developers.

The fourth essay (Chapter 5: Economic risk analysis of decentralized renewable energy infrastructures – A Monte Carlo Simulation Approach) complements the discussion of managerial challenges by the developed approach for a sophisticated risk management tool that advances existing instruments substantially as it allows simultaneous variation of multiple input factors. The additional value of this approach was tested within the research project "RePro – Ressourcen vom Land" where the combination of financial analysis with the developed Monte Carlo simulation tool helped to optimize the conceptual design of an investment project. Further implications were also discussed in the literature from the perspective of investors (Nasirov et al. 2015) and from a methodological perspective (Pai et al. 2015). From the perspective of transdisciplinarity, the developed approach has included several steps where actors from academia and practice collaborated to realize synergies. Accordingly, stakeholders involved within the research project “RePro – Ressourcen vom Land” contributed to define the models’ input parameters and in the process of developing forms for the display of results so that the applicability of the tool could be improved. However, for broader practical dissemination, further steps such as the development of a dataset for input factor values and related probability density functions could be useful.

The fifth and sixth essays brought findings regarding the third guiding question (see section 1.2.), i.e., regarding policy issues in the context of the “Energiewende”. The meta-analysis in the fifth essay (Chapter 6: Nudging as a new “soft” tool in environmental policy – An analysis based on insights from cognitive and social psychology) showed how useful it can be to expand the policy toolkit to induce behavioral changes and promote environmentally friendly behavior. Underlying this policy recommendation are insights from the behavioral sciences. Accordingly, human decision making is determined by two interacting cognitive processes, one rather intuitive and the other deliberate, so that policy measures to address both domains have to be developed. However, for practical implementation, several critical aspects have to be considered in this regard. Here, particularly the fact that personal attributes, social circumstances, and the broader perception on behavioral approaches in policy can influence the effectivity of behavioral policy interventions turned out to be a major concern.

Finally, the sixth essay (Chapter 7: Public-private partnership, incomplete contracts, and distributional fairness – when payments matter) focusses with a theoretical, microeconomic approach on the governance question of ownership allocation in a public-private partnership setting. In this context, the inclusion in the model of preferences for distributional fairness led to new findings compared with established literature as the investment incentives of involved parties are now determined not only by the chosen ownership structure but also by payments to the actors. Keeping in mind the dispersed structure of the renewable energy sector, this theoretically derived finding can have significant impact. Economic agents who act in a socially close setting where preferences for distributional equality can be relevant (e.g., the setting of a decentralized, small-scale renewable energy infrastructure) must include possible psychological effects in their considerations. Hence, an appeal to fairness concerns and the regulation of these fairness preferences through payments can lead to incentives for investment, in contrast to the standard model where only a variation of ownership structures can induce a change of incentives.

8.2. Summary of this thesis from a general perspective

As outlined in the introductory description of challenges in the context of the "Energiewende" (section 1.1.) and within the respective essays of this thesis, problem sets in the context of the "Energiewende" simultaneously concern several subject areas that interact with each other. Among these areas are technical, socioeconomic, legal, administrative, behavioral, as well as philosophical and ethical aspects (Creutzig et al. 2014). Hence, to provide useful analysis and suitable recommendations for action for the needs of many different stakeholders, holistic analysis approaches and solutions are needed that include insights from the above-mentioned various disciplines and perspectives. Through this, developed solutions such as analysis tools, processes, policies, and organizational settings are more resilient as they incorporate traits from various domains and therefore can absorb changing influences within the developed toolset instead of requiring a reorganization of processes and instruments (Schneider et al. 2014).

Accordingly, the importance of bottom-up approaches and citizen involvement for the progress of the "Energiewende" as revealed in the first essay is to some extent the materialization of a holistic approach to the governance of the German energy sector's sustainable transition.

Given the various constraints to investing in the renewable energy sector (e.g., transaction costs, hold-up problem due to relation-specific investments, high power-specific up-front capital costs, risks inherent to project finance) bottom-up approaches can help to overcome these mainly economically driven challenges through a set of social and behavioral solutions. Here, participative governance forms can contribute to conflict solving within organizations and trust building among actors with heterogeneous goal sets (Yildiz et al. 2015), help to foster mutual respect and collaboration among involved stakeholders, and finally develop additional benefits such as the building of social capital (Devine-Wright 2005; Walker et al. 2010).

A similar rationale is also reflected in the context of the theoretical analysis of ownership and investment incentives within a public-private partnership setting (essay no.

6/ chapter 7). The finding that preferences for distributional fairness can induce investments irrespective of the underlying ownership structure is particularly important in a decentralized context where social ties tend to be stronger than in a competitive market setting. Hence, inconveniences such as underinvestment can be overcome through solutions based on a holistic analytical approach that combines insights from organizational and behavioral sciences.

The idea of more comprehensive solutions through a holistic approach does not only apply to governance aspects and to the question of organizational settings but also to the development of instruments for project evaluation. Here, the participation of stakeholders in the development process of a specific analysis tool can contribute to improving the suitability of an instrument as it allows inclusion of different perspectives and reduces the complexity of displayed results, as was the case in the context of the Monte Carlo simulation tool presented in this thesis. In addition, the involvement of stakeholders in the development process can also foster the involved parties' trust toward the use of a specific tool and decisions derived with the help of an instrument. This not only applies to the presented tools here but also to other instruments of high relevance in the context of renewable energy infrastructures, such as multicriteria analysis (e.g., Haralambopoulos and Polatidis 2003; Pohekar and Ramachandran 2004; Wang et al. 2009) and strategic environmental assessment (e.g., Noble 2000; Jay 2010).

To conclude, the requirement of holistic research approaches and solutions for implementation in practice (e.g., organizational settings, analysis tools, development of legal norms, and administrative procedures) is not only the common denominator of this thesis but for research in the context of the "Energiewende", sustainability transitions, and climate change in general. The rationale behind this conclusion is that only more comprehensive approaches to research and governance can reflect the complexity and scope of challenges as well as the multiplicity of actors involved. However, more comprehensiveness often also goes along with more complexity. Against this background, transdisciplinarity also becomes more and more important as it reflects the aspect of more holistic approaches on the actor level. Here, the holistic characteristic is not only on an interdisciplinary basis but on the involvement of actors with different institutional backgrounds, i.e., academia and nonacademia. Consequently, this helps on the one hand to develop further research questions and methods and on the other hand reduces complexity through participation so that the transfer of findings from research is facilitated.

8.3. Implications for further research

The implications of the respective essays' findings for further research were already partly addressed in the conclusions section of the individual essays. Hence, this section only adds to the outlook that has been given in the previous sections and makes a final remark on methodical limitations.

Regarding organizational models for the financial participation of citizens, empirical insights on sociodemographic characteristics reveal that the group of citizen investors is composed of a rather homogeneous group of individuals[64] that do not reflect the sociodemographic characteristics of the society in general. Hence, from a perspective of participation and societal democratization arises the need for business models that allow integrating groups such as women, nongraduates, and younger citizens more into citizen-participation schemes in the renewable energy sector (Yildiz and Radtke 2015). This need is further strengthened from other perspectives as, for example, the dynamics in domains such as energy cooperatives decreases significantly (e.g., Müller and Holstenkamp 2015).

In this regard, a solution to raise participation among individuals from households with lower income can induce new dynamics. A currently elaborated approach in this direction is the so-called Consumer Stock Ownership Plan. This business model tries to enable private individuals to set up an energy project through the strategy of leveraged finance. Technically speaking, the necessary investment is mainly financed through debt finance. These loans are paid from revenues of the project and can be combined with public loan guarantees so that investing individuals do not have to invest their own financial resources. Consequently, households with lower income could be involved in citizen-participation schemes and help to turn individuals from consumers to (co-)producers and (co-)owners (Lowitzsch and Goebel 2013).

Furthermore, the development of a standardized toolset for project evaluation and the provision of this toolset for a broader audience is also a task for further research.

[64] The majority of citizen investors are men, older than 45 years, have a university degree, and an individual monthly gross income over 2,500 euros, respectively a monthly net household income of more than 2,500 euros (Radtke 2014; Rauschmayer et al. 2015).

Against the background of reduced feed-in tariffs and the envisioned[65] general introduction of auction mechanisms in the German renewable energy sector, realizing renewable energy projects through bottom-up approaches becomes more and more difficult as small-scale citizen participation deals with particular financial constraints (e.g., high relevance of sunk costs in the case of not being assigned the tender, lack of possibilities for risk diversification). Hence, a standardized toolset for project evaluation is essential for the further course of financial citizen participation as such a set of instruments can contribute to reducing the costs of project development. Consequently, the approaches taken in this thesis can be seen as a contribution to this task while further steps are necessary.

Finally, research in the context of governance and behavioral sciences offers starting points for further findings. As discussed in the conclusions to the sixth essay (section 7.5.), the relevance of social preferences in the context of renewable energy projects realized through bottom-up is mainly derived analytically from findings in social and behavioral science. Hence, empirical and experimental analysis to specify the influence of social preferences is needed. This could, in a further step, improve the conformity of theoretical models with reality and therefore contribute to better policy recommendations.

The challenge to include the complexity of real-life scenarios is likewise the connection to methodological limitations. In this regard, for a theoretical economic model to provide a framework for a sound analysis, the requirement is that the model's design should be in congruence with the conditions of reality, generality, and tractability (Camerer and Loewenstein 2004).

As the complexity of the modeled scenario (or problem set) increases, holistic approaches as presented in this thesis, particularly through the introduction of findings from behavioral economics, seem to be promising. Here, the condition of reality is explicitly the motivation for extending established analysis approaches and models. However, regarding the condition of generality and tractability, questions arise. In particular, the analysis conducted in the fifth essay revealed that behavioral patterns are highly context dependent. Identical measures can lead to different outcomes depending on the social context or an individual's preferences. Hence, the inclusion of insights from behavioral sciences into economic analysis has to account for this het-

[65] Auction mechanisms are now used in Germany in the context of solar energy from 2015. Furthermore, several other countries, such as Brazil, China, and South Africa have auction mechanisms already in use (e.g., Lucas et al. 2013).

erogeneity of individuals (see e.g., Meran and Schwarze 2015). Otherwise, limitations in regard to generality and tractability have to be considered when trying to develop models for analysis. In addition, the desire for more reality increases the complexity so that a trade-off between the simplicity of theoretical analysis models to derive general recommendations and the desire to depict real-life scenarios' complexity within a model has to be made.

8.4. Literature

Camerer, C.F./ Loewenstein, G.F. (2004): Behavioral Economics: Past, Present, Future. In: Camerer, C.F./ Loewenstein, G.F./ Rabin, M. [eds.]: Advances in Behavioral Economics. Princeton University Press (i.a.), Princeton, NJ (i.a.), 2004, pp. 3-52.

Creutzig, F./ Goldschmidt, J.C./ Lehmann, P./ Schmid, E./ von Blücher, F./ Breyer, C./ Fernandez, B./ Jakob, M./ Knopf, B./ Lohrey, S./ Susca, T./ Wiegandt, K. (2014): Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition. In: *Renewable and Sustainable Energy Reviews*, 38, 1015-1028.

Devine-Wright, P. (2005): Local aspects of UK renewable energy development: exploring public beliefs and policy implications. In: *Local Environment*, 10 (1), 57-69.

Fraune, C. (2015): Gender matters: Women, renewable energy, and citizen participation in Germany. In: *Energy Research & Social Science*, 7, 55-65.

Haggett, C./ Aitken, M. (2015): Grassroots Energy Innovations: the Role of Community Ownership and Investment. In: *Current Sustainable/Renewable Energy Reports*, 2 (3), 98-104.

Haralambopoulos, D.A./ Polatidis, H. (2003): Renewable energy projects: structuring a multi-criteria group decision-making framework. In: *Renewable Energy*, 28 (6), 961-973.

Höfer, H.H./ Rommel, J. (2015): Internal governance and member investment behavior in energy cooperatives: An experimental approach. In: *Utilities Policy*, 36, 52-56.

Jay, S. (2010): Strategic environmental assessment for energy production. In: *Energy Policy*, 38 (7), 3489-3497.

Lowitzsch, J./ Goebel, K. (2013): Vom Verbraucher zum Energieproduzenten. Finanzierung dezentraler Energieproduktion unter Beteiligung von Bürgern als Konsumenten mittels Consumer Stock Ownership Plans (CSOPs). In: *Zeitschrift für Neues Energierecht (ZNER)*, 17 (3), 237-244.

Lucas, H./ Ferroukhi, R./ Hawila, D. (2013): Renewable Energy Auctions in Developing Countries. International Renewable Energy Agency (IRENA), Abu Dhabi, United Arab Emirates, 2013.

Müller, J.R./ Holstenkamp, L. (2015): Zum Stand von Energiegenossenschaften in Deutschland: Aktualisierter Überblick über Zahlen und Entwicklungen zum 31.12.2014 [On the State of Energy Cooperatives in Germany: Updated Overview of Numbers and Developments As of 31 December 2014]. MPRA Paper No. 62072, University Library of Munich, Munich, Germany, 2015. URL: https://mpra.ub.uni-muenchen.de/62072/1/MPRA_paper_62072.pdf. (last time accessed 15.10.2015).

Nasirov, S./ Silva, C./ Agostini, C.A. (2015): Investors' Perspectives on Barriers to the Deployment of Renewable Energy Sources in Chile. In: Energies, 8 (5), 3794-3814.

Noble, B.F. (2000): Strategic environmental assessment: what is it? & what makes it strategic?. In: *Journal of Environmental Assessment Policy and Management*, 2 (2), 203-224.

Pai, F.Y./ Yeh, T.M./ Hung, Y.H. (2015): Analysis on Accuracy of Bias, Linearity and Stability of Measurement System in Ball screw Processes by Simulation. In: *Sustainability*, 7 (11), 15464-15486.

Pohekar, S.D./ Ramachandran, M. (2004)_ Application of multi-criteria decision making to sustainable energy planning – a review. In: *Renewable and Sustainable Energy Reviews*, 8 (4), 365-381.

Radtke, J. (2014): A closer look inside collaborative action: civic engagement and participation in community energy initiatives. In: *People, Place & Policy Online*, 8 (3), 235-248.

Rauschmayer, F./ Centgraf, S./ Masson, T. (2015): Ergebnisse der EnGeno Mitgliederbefragung von Energiegenossenschaften. Helmholtz - Zentrum für Umweltforschung (UFZ), Leipzig, Germany, 2015.

Romero-Rubio, C./ de Andrés Díaz, J.R. (2015): Sustainable energy communities: a study contrasting Spain and Germany. In: *Energy Policy*, 85, 397-409.

Vasileiadou, E./, Huijben, J.C.C.M./ Raven, R.P.J.M. (2015): Three is a crowd? Exploring the potential of crowdfunding for renewable energy in the Netherlands. In: *Journal of Cleaner Production*. Published as online first article. DOI 10.1016/j.jclepro.2015.06.028.

Schneider, C./ Achilles, B./ Merbitz, H. (2014): Urbanity and Urbanization: An Interdisciplinary Review Combining Cultural and Physical Approaches. In: *Land*, 3 (1), 105-130.

Walker, G./ Devine-Wright, P./ Hunter, S./ High, H./ Evans, B. (2010). Trust and community: Exploring the meanings, contexts and dynamics of community renewable energy. In: Energy Policy, 38 (6), 2655-2663.

Wang, J.J./ Jing, Y.Y./ Zhang, C.F./ Zhao, J.H. (2009): Review on multi-criteria decision analysis aid in sustainable energy decision-making. In: *Renewable and Sustainable Energy Reviews*, 13 (9), 2263-2278.

Yildiz, Ö./ Radtke, J. (2015): Energy Cooperatives as a Form of Workplace Democracy? – A Theoretical Assessment. In: *European Economic Sociology Newsletter*, 16 (3), 17-24.

Yildiz, Ö./ Rommel, J./ Debor, S./ Holstenkamp, L./ Mey, F./ Müller, J.R./ Radtke, J./ Rognli, J. (2015): Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda. In: *Energy Research & Social Science*, 6, 59-73.

Eidesstattliche Versicherung

Sehr geehrte Mitgliederinnen und Mitglieder des Promotionsausschusses,
sehr geehrte Gutachterinnen und Gutachter,

hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertation selbstständig verfasst, keine anderen als die angegebenen Literaturquellen und Hilfsmittel (z.B. Software zur Ausführung von Rechnungen) benutzt habe sowie alle Ausführungen, die anderen Schriften wörtlich oder sinngemäß entnommen wurden, kenntlich gemacht sind.
Textabschnitte, die auf der Basis eigener Veröffentlichungen in Zusammenarbeit mit weiteren Autoren entstanden sind, wurden einleitend zu jedem Kapitel ebenfalls mit der Benennung der beteiligten Personen gekennzeichnet. Auch weitere Personen wie Lektoren, die die einzelnen Aufsätze sprachlich korrigiert haben, oder Wissenschaftler, die inhaltliche Anmerkungen zu den jeweiligen Aufsätzen machten, wurden einleitend zu jedem Kapitel benannt. Die Darstellung des Eigenanteils des Verfassers dieser Dissertationsschrift an den jeweiligen Veröffentlichungen erfolgte auf separaten Erklärungen. Diese wurden dem Antrag auf Zulassung zum Promotionsverfahren an der Fakultät VII der Technischen Universität Berlin beigefügt.
Abschließend versichere ich, dass die vorliegende Arbeit in gleicher oder ähnlicher Fassung noch nicht Bestandteil einer Studien- oder Prüfungsleistung war und dass diesem Promotionsverfahren keine endgültig gescheiterten Promotionsverfahren vorausgegangen sind.

______________________ ______________________________

Ort, Datum Unterschrift des Verfassers