Risk and Return Management for the Heat Transition in Germany

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Please note: The author numbered the tables and figures consecutively for each section – also within Sections II, III, and IV with each section representing a research paper. The author provides references at the end of each section and each research paper, respectively.

Index of research papers

This doctoral thesis contains the following research papers:

Research paper 1 (RP1):

Töppel J, Tränkler T (2019) Modeling energy efficiency insurances and energy performance contracts for a quantitative comparison of risk mitigation potential.

In: *Energy Economics, 80, p. 842-859*

(VHB-JOURQUAL 3: category B; 5-Year Impact Factor: 4.963)

Research paper 2 (RP2):

Baltuttis D, Töppel J, Tränkler T, Wiethe C (2020) Managing the risks of energy efficiency insurances in a portfolio context: an actuarial diversification approach.

In: *International Review of Financial Analysis, 68, Article 101313*

(VHB-JOURQUAL 3: -; 5-Year Impact Factor: 1.729)

Research paper 3 (RP3):

Niemierko R, Töppel J, Tränkler T (2019) A D-vine copula quantile regression approach for the prediction of residential heating energy consumption based on historical data.

In: *Applied Energy, 233-234, p. 691-708*

(VHB-JOURQUAL 3: -; 5-Year Impact Factor: 7.888)

Research paper 4 (RP4):

Töppel J (2019) Ein Entscheidungsunterstützungssystem zur ökonomischen Bewertung von Mieterstrom auf Basis der Clusteranalyse.

In: *Tagungsband der 14. Internationalen Tagung Wirtschaftsinformatik, Siegen, Germany February 2019, p. 1478-1492*

(VHB-JOURQUAL 3: category C; 5-Year Impact Factor: -)

Research paper 5 (RP5):

Brinz N, Regal C, Schmidt M, Töppel J (2018) Reducing the pain of the inevitable: assisting IT project managers in performing risk management.

In: *Proceedings of the 39th International Conference on Information Systems (ICIS), San Francisco, USA, December 2018*
(VHB-JOURQUAL 3: category A; 5-Year Impact Factor: -)

I Introduction[1]

To achieve ambitious international climate goals will require imminent and deep reductions in anthropogenic greenhouse gas emission to decrease climate change's negative effects (Fawcett et al. 2015). The four key sectors industry, households, trade and services, as well as transport will account for annual global emissions of approximately 40 gigatons carbon dioxide (GtCO$_2$) in 2020 (Rogelj et al. 2016). To keep the global average temperature increase well below 2°C compared to pre-industrial levels, these emissions need to reduce to approximately five GtCO$_2$ by 2050 (Rockström et al. 2017). From a technical and economic perspective, the decarbonization targets are ambitious, but achievable (Rogelj et al. 2016). However, *low-carbon transitions* in the *electric energy* and *heat* areas are a prerequisite for fulfilling the decarbonization targets and affect all four key sectors (Geels et al. 2017). Moreover, sector-specific low-carbon transitions like the *transport transition* are indispensable (Geels 2012). All low-carbon transitions are strongly interconnected and have two things in common: They focus on renewable energy sources and energy efficiency (Patwardhan et al. 2012). Policymakers and practitioners must address these two commonalities jointly to ensure low-carbon transitions' successful realization. In the construction area, for example, only highly efficient building envelopes enable the use of high-efficiency, renewable heating systems, such as low-temperature waste heat and heat pumps. In Germany, the energy, heat, and transport transitions represent more than 75% of energy consumption and are, thus, core pillars for the national efforts in the climate protection field (Klaus et al. 2010). Low-carbon transitions involve several risks and business opportunities, which are presented in the following:

The *(electric) energy transition*, which the author defines as deactivating electricity generation units that rely on fossil fuels or nuclear energy and simultaneously expanding renewable energy sources (e.g., photovoltaic systems and wind turbines), is the most noticeable renewables development in recent years (Hake et al. 2015). Renewable energy sources often depend on external stochastic factors like solar radiation (e.g., influenced by clouds) or wind intensity. Consequently, the uncertainty about electricity supply fluctuations increases and poses several risks (Ludig et al. 2011). From a high-level perspective, owing to physical

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[1] Since a cumulative doctoral thesis naturally consists of individual research papers, this section, the beginning of Chapters II and III, as well as the last Chapter IV, partly consist of content that I extracted from the research papers included in this thesis. To facilitate reading, I omit these citations' standard labeling.

constraints, it is crucially important to balance electricity supply and demand to ensure stability. Consequently, a growing necessity for flexibility in electricity systems arises as a basic requirement for power system stability to avoid blackouts (Rammerstorfer and Wagner 2009). A promising approach in this context is using power demand flexibility (i.e., the capability to adjust the power demand) to balance demand and generation, known as demand response (Palensky and Dietrich 2011). Fridgen et al. (2016) analyzed flexibility's economic value and proved a great potential in terms of reduced energy costs or compensation payments for companies. Following Pepermans et al. (2005), ensuring a reliable supply necessitates a massive distributed energy generation expansion (small-scale electricity generation). However, investors and private households are still cautious, because the financial investment yields in renewable electricity generation are uncertain, as these investments depend on various risk factors, such as energy price development, technical performance, and weather conditions. For example, hail damage can cause notable losses in photovoltaic systems (Muehleisen et al. 2018) or interconnected technologies from different system providers bear legal risks, for example, claims-related warranty issues (Weeber et al. 2017). To address this problem, the German government supports decentralized electricity supply with various financial benefits like guaranteed feed-in tariffs and subsidies. In the multi-family house area, the landlord-to-tenant electricity supply model has great potential. In terms of this model, the landlord acts as an energy provider that supplies electricity from a photovoltaic system or from cogeneration units (e.g., fuel cell) to the tenants (Behr and Großklos 2017). Nevertheless, electricity accounts for only a fifth of German energy consumption and renewable energy's role in the transport and heat area remains critical (AGEB 2018).

The *transport transition*, defined as the process of converting transport and mobility to renewable energy sources, sustainable mobility (based on electricity from renewable sources, on bicycle and on foot), and interconnecting various forms of individual transport and local public transport (Canzler and Knie 2013), addresses the sector with the highest energy consumption in Germany (BMWi 2017). The electrification of vehicles is one of the most promising approaches for decreasing greenhouse gas emissions in the transport sector. Industry is making substantial efforts to replace gasoline-powered and diesel-powered vehicles with electric vehicles. However, scientists and practitioners must overcome several obstacles before electric vehicles can lever their ecological potential. According to the literature, electric vehicles have several negative connotations and risks like high purchase costs, limited battery longevity, battery range, long recharging time, and adverse environmental impacts arising from charging electricity unsustainably (Egbue and Long 2012). Moreover, the availability of special metals used in electric vehicles (e.g., neodymium for electric motors) is subject to a multitude of geopolitical supply risks and questionable mining practices (Gemechu et al. 2017). Furthermore, a widespread charging infrastructure is a prerequisite for a successful transport transition and is tantamount to enormous investments. In this vein, Liu and Wei (2018) discuss several of the charging infrastructure investments' risk categories like legal, economic, social, and technical risks, and they develop a specific risk management framework. At the same time, the transport transition also shows great economic potential and has already spawned the first specialized companies in this field. For example, the Berlin startup, ubitricity, transforms ordinary streetlights into electric car charging points. Germany's Post AG, which originally wanted to develop an electric vehicle for its own use purposes, today sells electric box wagons. Furthermore, since electric cars support demand response management, they have potential cost advantages, owing to flexibility via their batteries (Siano 2014). Nevertheless, the largest part of energy consumption is attributable to heat, with an overarching share of approximately 56% in Germany (AGEB 2018).

The *heat transition* is defined as expanding renewable energy sources and energy efficiency in heat generation and demand. Heating energy consumption can be divided into two major areas: building heat (space heating, space cooling, and hot water) with a 61% share and industrial process heat with a 39% share (AGEB 2018). Greenhouse gas emissions from building heat (residential and non-residential) currently account for around 20% of energy-related emissions in Germany (Fraunhofer IWES/IBP 2017). Although this share seems relatively low at first glance, it is obscured by the coal-fired electricity's high CO_2 values in the energy sector. Researchers can therefore expect this share to increase significantly after the planned coal phase-out. The German government’s plan to reduce the building heat's fossil primary energy consumption by 80% before the year 2050 compared to 1990, bases on two pillars of energetic retrofitting: thermal insulation (energy efficiency) and using renewable energies for heating systems. Thermal insulation includes insulating the outer wall, roof, and cellar, as well as the window panes (thermal insulation glazing). In many residential buildings, thermal insulation can potentially reduce emissions by about 40% to 50% (Rockström et al. 2017). Efficient heating systems like heat pumps, solar systems, and biomass boilers can further reduce the need for fossil fuels. However, there are several barriers, for example, market failures like environmental externalities and imperfect information that hinder energy efficiency investments (Brown 2001). Moreover, energetic retrofitting investments relate to a set of risks that academics can generally sort into economic, contextual, technological, operational, as well as measurement and verification risks (Mills et al. 2006). In particular, evaluating the achieved energy bill savings and, thus, the underlying investment, mainly depends on future energy prices and energy efficiency performance (Lee et al. 2015). Unfortunately, energy retrofitting's energy efficiency performance exhibits a sizeable variance. For example, Galvin (2014), demonstrated this variance by comparing 30 apartments, which had similar physical properties, before and after the energetic retrofitting. The same is true for the energy prices (Chan and Grant 2016). Consequently, many property owners hardly utilize their energy efficiency potential, because they perceive the risks as too high, which leads to a systematic under-investment (Jakob 2006). For Germany, this effect is particularly evident in the energetic retrofitting rate, which is currently only 1% per year instead of the 2% required to achieve the national climate targets (Hesse and Veit 2016). The risk of the expected energy bill savings remains a major obstacle for value-based investment decisions (Amasyali and El-Gohary 2018). In the business sector, energy service companies (ESCOs) already offer comprehensive, energy-related outsourcing services, such as maintenance, financing, installation, operation, and risk transfer methods, mostly related to energetic retrofitting (Bundesstelle für Energieeffizienz 2018). While ESCOs provide instruments for financial risk mitigation in the business or public sector, similar solutions for private households are scarce, even though this customer group should be especially receptive to such risk mitigation (Häckel et al. 2017). However, the owner-occupied household customer group is an important decision maker on the issue of heat transition as these households are responsible for approximately 25% of Germany's heating energy (Statista 2019; AGEB 2018).

Furthermore, connecting the electricity, heat, and transport areas must play an important role to achieve low-carbon transitions in the future (Ausfelder et al. 2017). For instance, experts can connect residential heating systems also to electricity grids, whereby the thermal energy operates as energy storage or backup for peak loads (Tan et al. 2016). Scientific literature summarizes these approaches as sector coupling (Brown et al. 2018). In order to promote low-carbon transitions, this doctoral thesis attempts to develop methods for quantifying and managing risks in this context. Generally, academics can arrange risk management along the risk management cycle in four phases, namely identification, quantification, controlling, and monitoring (Hallikas et al. 2004), which helps categorize the presented research papers. According to Geels (2012), low-carbon transitions will boost innovative business models and require enormous investments, which require an integrated risk and return management. For example, Germany's Federal Ministry for Economic Affairs and Energy estimates that the building sector (residential and non-residential) requires additional annual investments of approximately 15 billion Euro to achieve efficiency targets before 2050, which therefore represents the most expensive low-carbon transition in Germany (BMWi 2014; Die Bundesregierung 2016). The literature and practice show that the necessary investments go along with a multitude of risks like market risks, technology-specific risks, or IT risks (Mills 2003a; Egbue and Long 2012; Ludig et al. 2011). Since risk play a decisive role in the investment decisions, suitable risk and return management methods are essential to enable low-carbon transitions; this thesis addresses these methods as depicted in Figure I.1-1:

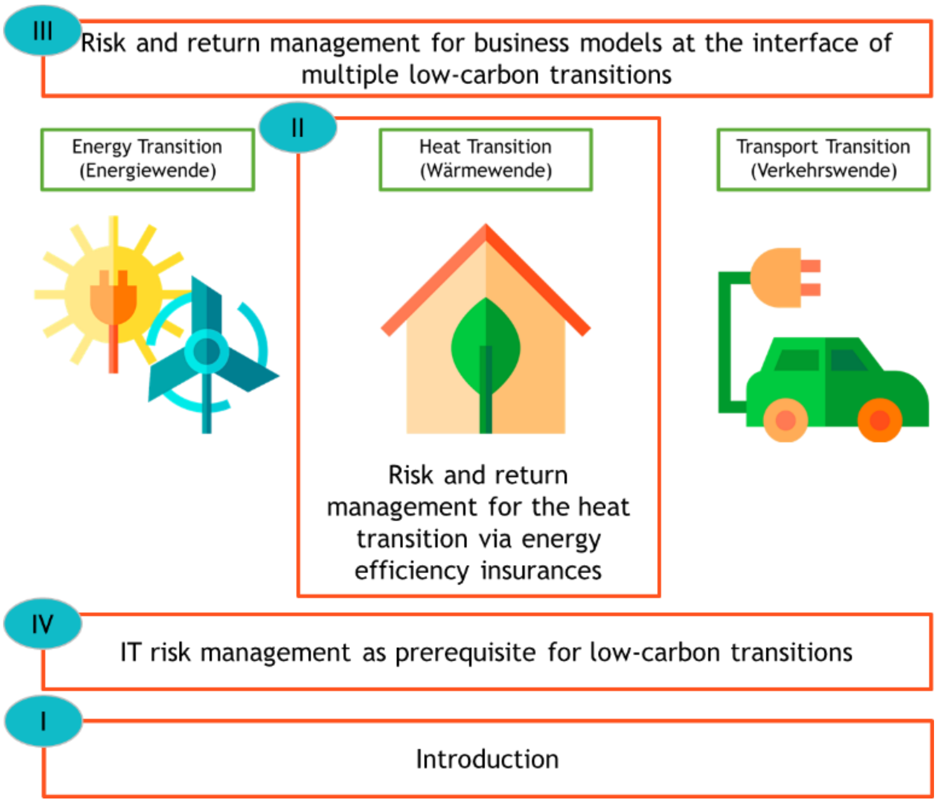

Figure I.1-1: Structure and research topics in the doctoral thesis

In order to contribute to the knowledge at the interface between the Finance, Information and Energy Management disciplines, the author presents risk and return management approaches for the heat transition (Chapter II), for sustainable business models at the interface of multiple low-carbon transitions (Chapter III), and for the related IT (Chapter IV).

Regarding risk and return management for the heat transition: Several scientific studies confirm the importance of economic factors as barriers in the energy efficiency investment context (Egbue and Long 2012). Achtnicht and Madlener (2014) use a choice experiment to confirm that investors are more likely to invest if a project exhibits attractive payback periods or if there is a technological need like a heating system needing a quick refurbishment. However, the choice experiment's assumption that energetic retrofitting investments exhibit an actual payback period of ten years, is questionable. Energy engineers and consultants traditionally estimate initial payback periods as best estimates without a profound economic perspective and may thus unsettle investors (Jackson 2010). The accurate prediction of energy efficiency gains is a prerequisite for private investments. The common, standardized engineering methods quantify theoretical energy consumption based on standard conditions and physical equations. Thereby, these engineering methods often neglect individual factors like occupant behavior, which is a source of considerable variance (Ahmad and Culp 2006; Masa-Bote and Caamaño-Martín 2014; Rangaraju et al. 2015). Despite current policy measures, investors (e.g., professionals or private households) bear all the energy bill saving risks, which may vary, owing to inadequate planning, construction defects, or adverse energy price developments. Consequently, evaluating the expected net present value of the cumulative energy bill savings compared to the initial investments, remains challenging and a major obstacle for value-based investment decisions.

The advancing digitalization creates an amount of smart meter data and enables digital business models built on this smart meter data, which may contribute to overcome the above mentioned obstacle (Amasyali and El-Gohary 2018). Furthermore, the upsurge in machine learning methods and the improved data availability support the sustainable technology and business model expansion. For instance, Mathew et al. (2005) suggest a data-based actuarial approach to assess energy efficiency investments and related risks' economic viability. Mills (2003a) introduces a self-styled energy efficiency insurance (EEI) that may help overcome the energy efficiency investments' barriers. In exchange for a premium payment, an EEI insures an energy efficiency investment's predefined financial performance, such as the minimum energy bill savings or the maximum energy bill costs. Consequently, investors obtain certainty and practitioners may shorten their energy consulting efforts, because the essential consulting topic, profitability, is simplified. Profitability's simplification and acceleration mainly result from practitioners not having to discuss the possible negative scenarios in detail, since they are already covered by the EEI. For the insured, however, the premium payments reduce the investment's profitability. Despite the EEI possibly catalyzing significant energetic retrofitting investments, the EEI has not received wide academic attention in either the private or the public sector (Micale and Deason 2014). Consequently, Chapter II of this doctoral thesis examines the statistical methods' applicability to the EEI pricing in the energetic retrofitting context. The author therefore introduces insurance premium calculation models, analyzes the diversification effects in the context of regulatory requirements (Solvency II) and also analyzes customer-specific risks. These statistical approaches potentially provide the basis for disseminating the EEI as risk transfer instrument for the heat transition.

Regarding risk and return management for business models at the interface of multiple low-carbon transitions: As stated, phasing out existing carbon-intensive systems accelerates the energy, heat, and transport transitions and creates space for niche innovations and new business models. According to Richter (2013), business model innovations will be crucial to master low-carbon transitions. Loorbach and Wijsman (2013) argue that there is a growing trend of businesses and industries that mitigate negative environmental impacts. Consequently, companies start to fundamentally rethinking existing businesses in light of low-carbon transitions. The insurance industry's EEI might be an example of this paradigm shift (see Chapter II). Moreover, connecting multiple low-carbon transition innovations is a particularly promising approach. One such example is sector coupling, defined as coupling different energy sectors and energy forms (Geels et al. 2017). For instance, the vehicle-to-grid technology is at the interface between the energy transition and transport transition, and allows for bidirectional energy exchange between electrified mobility systems and the power grid. This technology can facilitate electric vehicle distribution; the technology also supports load balancing if the vehicle batteries are used intelligently (Sovacool et al. 2017). The landlord-to-tenant electricity supply model, which was originally intended for the energy transition, also supports multiple low-carbon transitions. Landlords simultaneously benefit from the energy, heat, and transport transition by providing electricity for household and mobility usage. In addition, a cogeneration unit's waste heat (e.g., fuel cells) is useful for hot water and space heating. Nevertheless, Yildiz (2014) claims that the risk and return management for these decentralized renewable energy infrastructures is a complex issue and that standardized investment evaluation methods are scarce. The literature therefore presents several approaches for the purported building energy modelling in order to predict the related investments' technical performance (Amasyali and El-Gohary 2018). However, to the author's best knowledge, the integrated consideration of technical performance and personal factors from a risk and return perspective has not received wide academic attention in the context of the landlord-to-tenant electricity supply model. Consequently, Chapter III presents parts of a data-based decision support system for landlord-to-tenant electricity supply investments in order to exemplarily demonstrate risk and return management at the interface of multiple low-carbon transitions.

Regarding IT risk management for low-carbon transitions: Multiple low-carbon transition solutions and services require the application of digital technologies and the comprehensive interconnection of the distributed infrastructures, products, customers, and value chain partners; these transition solutions and services also create a variety of new risks. As a result, especially information-based risks (e.g., cybersecurity or privacy) are crucially important, because properly functioning information systems and reliable information flows have become essential for operating reliable digital business models and services (Dellermann et al. 2017). IT systems are therefore essential elements of an organization’s value creation and their outage or insecurity can detrimentally affect business operations (Melville et al. 2004). For example, Balda et al. (2017) discuss the strong relationship between cyber security and energy security, while McDaniel and McLaughlin (2009) state the importance of data privacy risks in smart grids and homes. Specifically companies have to deal with these new risks via their risk management as part of digital product and service development in the low-carbon transition context. Especially in the energy management area and the related critical infrastructure, the IT solutions' reliability and security play a decisive role. This doctoral thesis therefore provides a clearly defined method that addresses IT risk management in the context of digital product and business model development (Chapter IV).

In summary, low-carbon transitions pose challenges regarding risk and return management and offer new business opportunities, which the author addresses in this doctoral thesis. The following Section I.1 illustrates this thesis's objectives and structure. In the subsequent Section I.2, the author embeds the corresponding research papers in the research context and highlights the fundamental research questions.

I.1 Objectives and structure of this thesis

This doctoral thesis's main objective is to contribute to the low-carbon transitions' risk and return management. Thereby, this doctoral thesis identifies and addresses research questions that support economic investment evaluations in the energy, heat, and transport transition context. Table I.1-1 gives an overview of this thesis's pursued objectives and structure.

I	**Introduction**
Objective I.1:	Outlining the motivation, objectives, and the structure of this doctoral thesis
Objective I.2	Embedding the included research papers into this thesis's context and formulating fundamental research questions
II	**Risk and return management for the heat transition**
Objective II.1:	Enabling energy efficiency insurance pricing and comparing the risk-mitigation capability of different contract designs when applied to energetic retrofitting
Objective II.2:	Reducing the insurance companies' regulatory costs by analyzing the diversification effects in diversified portfolios that contain energy efficiency insurance contracts
Objective II.3:	Improving the risk assessment of individual energy efficiency insurance contracts by providing a quantile-based energy forecast model
III	**Risk and return management for business models at the interface of the energy, heat, and transport transition**
Objective III.1:	Improving the evaluation of landlord-to-tenant electricity supply investments by providing a data-based approach that considers the tenants' individual load profiles
IV	**IT risk management as prerequisite for low-carbon transitions**
Objective IV.1:	Providing a clearly defined IT risk management method as an integral part for developing and implementing digital solutions for low-carbon transitions
IV	**Results and future research**
Objective V.1:	Presenting the key findings of this thesis
Objective V.2:	Identifying and highlighting future research areas

Table I.1-1: Objectives and structure of the doctoral thesis.

I.2 Research context and research questions

In the following, the author motivates the research context of Chapters II, III, and IV, including research papers RP1 to RP5. As low-carbon transitions and related investments require adequate risk and return management to overcome existing barriers, this doctoral thesis aims at contributing to these challenges by focusing on the heat transition (Chapter II). The author also discusses an exemplary business model at the interface of multiple low-carbon transitions in the investment evaluation context (Chapter III) and an IT risk management method in the low-carbon transition context (Chapter IV).

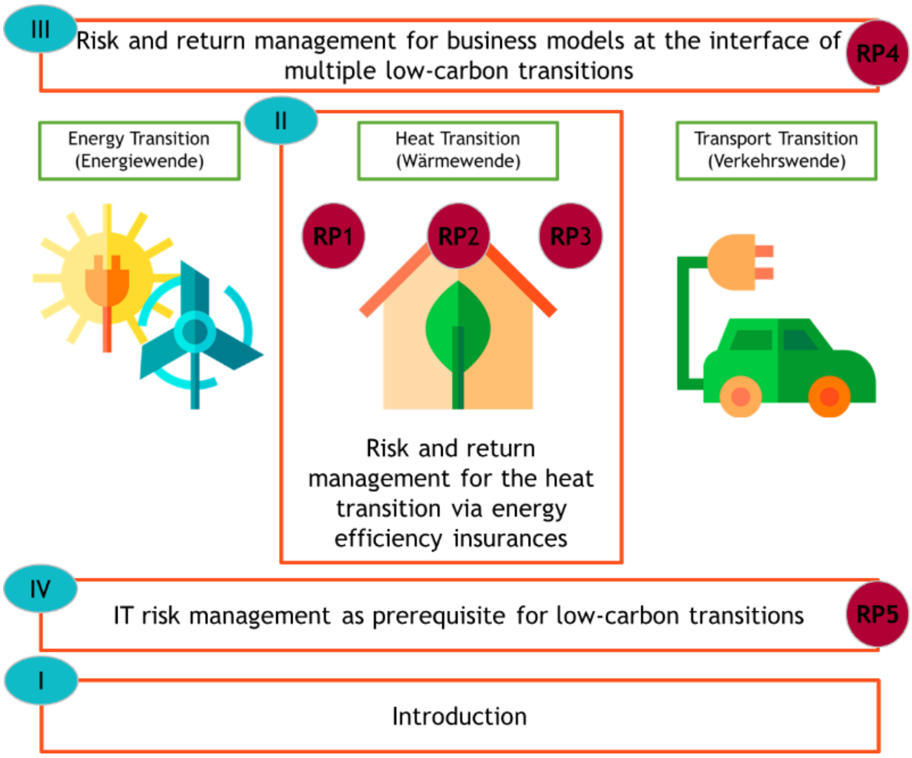

Figure I.2-1: Research papers included in the doctoral thesis

Figure I.2 1 provides an overview of the research papers included in this doctoral thesis. In Chapter II, research paper RP1 quantitatively evaluates energy efficiency insurance contracts and compares the different contract designs' risk mitigation potential. Research paper RP2 discusses the diversification effects between energy efficiency insurance products, property insurance products, and financial derivatives against the background of Solvency II. To complement this chapter, research paper RP3 analyses the customer-specific risk of energy retrofitting investments. In Chapter III, research paper RP4 addresses the landlord-to-tenant electricity supply model's investment evaluation. Since academics regard the necessary IT infrastructures for electricity, heat, and transport as critically important, research paper RP5 in Chapter IV deals with IT risk management as an important prerequisite for digital solutions in the low-carbon transition context to fulfill strict requirements (e.g., robustness against risks like natural disasters, cyber-attacks or system reliability). In the following, the author embeds the research papers, which are part of this doctoral thesis, in the research context and motivate the research questions with regard to the above stated objectives.

I.2.1 Chapter II: Risk and return management for the heat transition via energy efficiency insurances

Adequate risk and return management approaches may promote investments in the heat transition context, which is the most expensive and the most ambitious low-carbon transition in Germany (BMWi 2014; Die Bundesregierung 2016). According to Jackson (2010), financial risk mitigation plays a decisive role in managing the reported energy efficiency investment risk and overcoming the risk-related barriers. Against this backdrop, the insurance industry plays a central role in efforts to facilitate worldwide low-carbon transitions (Tucker 1997). As outlined above, energy efficiency insurances can provide a large share of benefits, thereby enabling the insurance industry to fulfil its responsibilities. Owing to the standard designs' relatively low variation and dispersion, the 16 million one-family and two-family homes in Germany (Destatis 2018a) are particularly suitable for standardized insurance products that address energetic retrofitting investments based on statistical methods. To the author's best knowledge, insurance premium calculation models for energy efficiency insurances, as well as the analysis of potential diversification effects, have not yet received wide academic attention. Consequently, Chapter II examines the statistical methods' applicability in the energetic retrofitting investment context for one-family and two-family homes as basis for disseminating energy efficiency insurances.

Research paper 1 (RP 1)*: "Modeling energy efficiency insurances and energy performance contracts for a quantitative comparison of risk mitigation potential"*

RP1 introduces a comprehensive model that forecasts the energetic retrofitting investments' energy bill savings, which is the basis of the energy efficiency insurance's fair premium calculation. Following Mills et al. (2006), the premium pricing in RP1 comprises economic, contextual, technology, and operation risks to ensure practical applicability. Existing risk transfer contracts in the business sector, which energy service companies operating as full-service providers offer (Li et al. 2014), inspired the forecasting model approach. On this basis, the study uses statistical risk measures (e.g., standard deviation) and Prospect Theory to compare the different contract designs' risk mitigation potential (Tversky and Kahneman 1992). Thereby, the analysis considers transaction costs in detail, because these costs vary significantly depending on the contract design (e.g., expensive engineering reports to verify reimbursement payments). Consequently, in accordance with Objective II.1 in Table I.1-1, research paper RP1 addresses the following research questions:

- How can energy efficiency insurances for energetic retrofitting be priced based on quantitative modelling of underlying risks and real-world data?
- How can the risk mitigation potential of varying efficiency insurance contract designs be analyzed?

Research paper 2 (RP 2)*: “Managing the risks of energy efficiency insurances in a portfolio context: an actuarial diversification approach”*

Increasing the regulation and rating agency requirements have promoted risk management approaches for insurance companies (Ai et al. 2018). Solvency II's strict requirements emphasize the diversification effects' decisive role, since these effects can significantly reduce the prescribed risk capital requirements and associated capital costs (Arbenz et al. 2012). Nevertheless, the literature on energy efficiency insurances from an insurer’s portfolio perspective is scarce, even though beneficial diversification effects can theoretically emerge. Consequently, RP2 provides a first quantitative modeling approach for the diversification effect analysis based on three levels: collective risk diversification (pooling homogeneous insurance contracts), cross-product line diversification (risk reduction via correlations between different insurance product portfolios), and financial hedging (Gatzert and Wesker 2012). Following Markowitz’ portfolio theory, this study empirically analyzes diversification effects relying on extensive real-world data sets. Consequently, in accordance with Objective II.2 in Table I.1-1, research paper RP2 addresses the following research questions:

- How can diversification effects of long-term, illiquid energy efficiency insurance portfolios be quantified from an insurance company's perspective?
- How do energy efficiency insurances change the diversified insurance portfolios' financial hedging strategy?

Research paper 3 (RP 3): *"A D-vine copula quantile regression approach for the prediction of residential heating energy consumption based on historical data"*

The literature presents several approaches for the purported building energy modelling, which aims to predict the technical performance of energetic retrofitting investments (Swan and Ugursal 2009). In recent years, several data-based energy prediction models emerged, using algorithms based on least square regressions, artificial neural networks, and support vector machines (Chou and Bui 2014). Owing to the huge influence of occupant behavior, households exhibit a notable energy consumption variance, despite their building components and characteristics – as potential input variables for prediction models – being equal (Galvin 2014). Moreover, the literature observes a more wasteful occupant behavior after energetic retrofitting investments and calls this change the rebound effect (Greening et al. 2000). Consequently, the training data for energy prediction models' training data for also reflects this high variance, which hampers the applicability of point estimation methods (Geman et al. 1992). To address this obstacle, Kaza (2010) emphasizes quantile regression analysis to consider the entire distribution of energy consumption instead of focusing on the conditional average. RP3 builds on this suggestion and models a quantile regression for predicting residential heating energy consumption via a D-vine copula. The calculated quantiles allow a more precise risk analysis of energetic retrofitting investments compared to the estimators for the expected energy consumptions. Consequently, in accordance with Objective II.3 in Table I.1-1, research paper RP3 addresses the following research questions:

- How can researchers apply D-vine copula quantile regressions to predict residential heating energy consumption?
- How does occupant behavior vary after energetic retrofitting measures under consideration of the household-specific energy consciousness?

I.2.2 Chapter III: Risk and return management for business models at the interface of the energy, heat, and transport transition

Research paper 4 (RP 4): *"Ein Entscheidungsunterstützungssystem zur ökonomischen Bewertung von Mieterstrom auf Basis der Clusteranalyse"*

Low-carbon transitions gain momentum when multiple innovations are connected (Geels et al. 2017). On this basis, new solutions and business models emerge that simultaneously influence multiple low-carbon transitions. For instance, the vehicle-to-grid technology, which allows bidirectional energy exchange between the electric vehicles and the power grid, can facilitate the electric vehicles; this technology also mitigates the wind and solar electricity's volatility problems if vehicle batteries support load balancing (Sovacool et al. 2017). Residential heating systems like heat pumps can also be connected to electricity grids, whereby the thermal energy is used as energy storage (e.g., increase a thermal buffer tank's temperature) or as back-up for peak loads (e.g., activate a heat pump's immersion heater). The above mentioned landlord-to-tenant electricity supply model is a business model that addresses the energy, heat, and transport transitions. Thereby, the landlord provides electricity for household usage or for electric vehicles. Furthermore, the usage of cogeneration units (e.g., fuel cells) offers the possibility of utilizing the resulting waste heat for hot water and space heating. In order to convince tenants to participate, the landlord undercuts the electricity's market price, as he particularly benefits from the tenants' electricity consumption. Nevertheless, the landlord can charge significantly higher electricity prices to tenants in comparison to feed-in tariffs. All these sector coupling approaches bear several risks, for example, owing to the increasing degree of interdependencies and the increasing complexity. Consequently, Chapter III provides parts of a decision support system for the economic evaluation of landlord-to-tenant electricity supply investments to exemplarily demonstrate data-based risk and return management for business models at the interface of the energy, heat, and transport transition. With decreasing local power generation costs (especially photovoltaic systems) and increasing energy prices for electricity (private households), decentralized power generation and direct on-site consumption becomes increasingly attractive (Nestl and Kunz 2014). In 2017, the German government passed a law to promote landlord-to-tenant electricity supply models and tried to remove existing legal barriers to encourage decentralized power generation. For the decentralized electricity models' economic evaluation, it is particularly important to consider household-specific consumption profiles, as well as photovoltaic electricity profiles, because the amount of directly consumed electricity generates different revenues than the revenues generated by the amount of electricity fed into the grid (Behr and Großklos 2017). RP4 therefore provides parts of a decision support system based on smart meter data for this business model's investment evaluation. A cluster analysis is performed to determine different electricity consumption profiles. Next, the clusters' expected profiles are used to forecast the tenants' electricity consumption patterns based on their demographic and socio-economic characteristics. In sum, RP4 addresses Objective III.1 in Table I.1-1 by asking the following research question:

- How can a decision support system based on smart meter data predict a property's energy consumption profile for the economic evaluation of landlord-to-tenant electricity supply models?

I.2.3 Chapter IV: IT risk management as prerequisite for low-carbon transitions

Research paper 5 (RP 5): *“Reducing the pain of the inevitable: assisting IT project managers in performing risk management”*

Since academics regard the necessary electricity, heat, and, transport infrastructures as critically important, the solutions in this context are often subject to strict requirements with regard to their robustness against risks like natural disasters, cyber-attacks, and system reliability (Chapman et al. 2013). This specifically applies to the IT infrastructures, since data availability already plays a decisive role and this role will increase in the future (Ramchurn et al. 2012).Consequently, practitioners have to consider IT risks if they develop new IT-based innovations and digital solutions for low-carbon transitions (Rot 2008). Since IT landscapes usually change and since companies usually develop innovations in projects, the (IT) risk management within these projects plays a decisive role (Zissis and Lekkas 2012). Chapter IV therefore provides a clearly defined method that establishes risk management as a crucial part of IT project management. To support IT project risk management, RP5 presents an integrated method that connects the knowledge of IT risks with risk-relevant project characteristics to identify, quantify, and mitigate risks.

RP5 conducts a single case study evaluation by deploying a software prototype, which has been evaluated by more than 20 participating IT projects. In sum, RP5 addresses Objective IV.1 in Table I.1-1 by asking the following research question:

- Is it feasible to develop a method that enables standardized IT risk assessments and benefits the user in terms of time saved via the constant quality of the results?

I.2.4 Section IV: Results and Future Research

After the introduction, which aims at outlining this thesis's objectives and structure, as well as motivating the research context and formulating the research questions, the research papers are presented in Sections II, III, and IV. Subsequently, Section V presents the key findings and highlights areas for future research in the field of risk and return management for low-carbon transitions and especially for the heat transition.

I.3 References

Achtnicht, Martin; Madlener, Reinhard (2014): Factors influencing German house owners' preferences on energy retrofits. In: Energy Policy 68, pp. 254–263.

AGEB (2018): Auswertungstabellen zur Energiebilanz Deutschland. Unter Mitarbeit von AG Energiebilanzen e.V. Hg. v. Arbeitsgemeinschaft Energiebilanzen. Available online at https://www.ag-energiebilanzen.de/, zuletzt geprüft am 01.04.2019.

Ahmad, Mushtaq; Culp, Charles (2006): Uncalibrated Building Energy Simulation Modeling Results. In: HVAC&R Res. 12 (4), pp. 1141–1155.

Ai, Jing; Bajtelsmit, Vickie; Wang, Tianyang (2018): The Combined Effect of Enterprise Risk Management and Diversification on Property and Casualty Insurer Performance. In: Journal Risk and Insurance 85 (2), pp. 513–543.

Amasyali, Kadir; El-Gohary, Nora M. (2018): A review of data-driven building energy consumption prediction studies. In: Renewable and Sustainable Energy Reviews 81, pp. 1192–1205.

Arbenz, Philipp; Hummel, Christoph; Mainik, Georg (2012): Copula based hierarchical risk aggregation through sample reordering. In: Insurance: Mathematics and Economics 51 (1), pp. 122–133.

Ausfelder, Florian; Drake, Frank-Detlef; Erlach, Berit; Fischedick, Manfred; Henning, Hans Martin; Kost, Christoph Philipp et al. (2017): "Sektorkopplung" - Untersuchungen und Überlegungen zur Entwicklung eines integrierten Energiesystems. München, Halle (Saale), Mainz: acetech - Deutsche Akademie der Technikwissenschaften e.V; Deutsche Akademie der Naturforscher Leopoldina e.V. - Nationale Akademie der Wissenschaften; Union der Deutschen Akademien der Wissenschaften e.V (Schriftenreihe Energiesysteme der Zukunft).

Balda, Juan Carlos; Mantooth, Alan; Blum, Rick; Tenti, Paolo (2017): Cybersecurity and Power Electronics: Addressing the Security Vulnerabilities of the Internet of Things. In: IEEE Power Electron. Mag. 4 (4), pp. 37–43.

Behr, Iris; Großklos, Marc (2017): Praxishandbuch Mieterstrom. Fakten, Argumente und Strategien. Wiesbaden: Springer Fachmedien Wiesbaden. Available online at https://ebookcentral.proquest.com/lib/gbv/detail.action?docID=4872976.

BMWi (2014): Sanierungsbedarf im Gebäudebestand. Ein Beitrag zur Energieeffizienzstrategie Gebäude. Hg. v. Bundesministerium für Wirtschaft und Energie. Berlin.

BMWi (2017): Energieeffizienz in Zahlen. Unter Mitarbeit von Bundesministerium für Wirtschaft und Energie. Berlin. Available online at https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/energieeffizienz-in-zahlen.pdf?__blob=publicationFile&v=10, zuletzt geprüft am 01.04.2019.

Brown, Marilyn A. (2001): Market failures and barriers as a basis for clean energy policies. In: Energy Policy 29 (14), pp. 1197–1207.

Brown, T.; Schlachtberger, D.; Kies, A.; Schramm, S.; Greiner, M. (2018): Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system. In: Energy 160, pp. 720–739.

Bundesstelle für Energieeffizienz (BfEE) (Hg.) (2018): Empirische Untersuchung des Marktes für Energiedienstleistungen, Energieaudits und andere Energieeffizienzmaßnahmen. Endbericht BfEE 04/17. Eschborn.

Canzler, Weert; Knie, Andreas (2013): Schlaue Netze. Wie die Energie- und Verkehrswende gelingt. 1. Aufl. s.l.: oekom verlag. Available online at http://www.content-select.com/index.php?id=bib_view&ean=9783865815651.

Chan, Joshua C.C.; Grant, Angelia L. (2016): Modeling energy price dynamics: GARCH versus stochastic volatility. In: Energy Economics 54, pp. 182–189.

Chapman, Lee; Azevedo, Juliana Antunes; Prieto-Lopez, Tatiana (2013): Urban heat & critical infrastructure networks: A viewpoint. In: Urban Climate 3, pp. 7–12.

Chou, Jui-Sheng; Bui, Dac-Khuong (2014): Modeling heating and cooling loads by artificial intelligence for energy-efficient building design. In: Energy and Buildings 82, pp. 437–446.

Dellermann, Dominik; Fliaster, Alexander; Kolloch, Michael (2017): Innovation risk in digital business models: the German energy sector. In: Journal of Business Strategy 38 (5), pp. 35–43.

Destatis (2018): Gebäude und Wohnungen. Bestand an Wohnungen und Wohngebäuden Bauabgang von Wohnungen und Wohngebäuden Lange Reihen ab 1969 - 2017. Hg. v. Statistisches Bundesamt (5312301177004). Available online at https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Wohnen/_inhalt.html, zuletzt geprüft am 04.04.2019.

Die Bundesregierung (Hg.) (2016): Was bringt, was kostet die Energiewende. Available online at https://www.bundesregierung.de/breg-de/themen/energiewende/was-bringt-was-kostet-die-energiewende-394146, zuletzt geprüft am 04.04.2019.

Egbue, Ona; Long, Suzanna (2012): Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. In: Energy Policy 48, pp. 717–729.

Fawcett, Allen A.; Iyer, Gokul C.; Clarke, Leon E.; Edmonds, James A.; Hultman, Nathan E.; McJeon, Haewon C. et al. (2015): CLIMATE POLICY. Can Paris pledges avert severe climate change? In: Science (New York, N.Y.) 350 (6265), pp. 1168–1169.

Fraunhofer IWES/IBP (2017): Wärmewende 2030. Schlüsseltechnologien zur Erreichung der mittel- und langfristigen Klimaschutzziele im Gebäudesektor. Studie im Auftrag von

Agora Energiewende. Hg. v. Agora Energiewende. Available online at https://www.agoranergiewende.de/fileadmin2/Projekte/2016/Sektorueberg_EW/ Waermewende-2030_WEB.pdf, zuletzt geprüft am 01.04.2019.

Fridgen, Gilbert; Häfner, Lukas; König, Christian; Sachs, Thomas (2016): Providing Utility to Utilities: The Value of Information Systems Enabled Flexibility in Electricity Consumption. In: JAIS 17 (8), pp. 537–563.

Galvin, Ray (2014): Making the 'rebound effect' more useful for performance evaluation of thermal retrofits of existing homes: Defining the 'energy savings deficit' and the 'energy performance gap'. In: Energy and Buildings 69, pp. 515–524.

Gatzert, Nadine; Wesker, Hannah (2012): A Comparative Assessment of Basel II/III and Solvency II. In: Geneva Pap Risk Insur Issues Pract 37 (3), pp. 539–570.

Geels, Frank W. (2012): A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. In: Journal of Transport Geography 24, pp. 471–482.

Geels, Frank W.; Sovacool, Benjamin K.; Schwanen, Tim; Sorrell, Steve (2017): Sociotechnical transitions for deep decarbonization. In: Science (New York, N.Y.) 357 (6357), S. 1242–1244.

Geman, Stuart; Bienenstock, Elie; Doursat, René (1992): Neural Networks and the Bias/Variance Dilemma. In: Neural Computation 4 (1), pp. 1–58.

Gemechu, Eskinder D.; Sonnemann, Guido; Young, Steven B. (2017): Geopolitical-related supply risk assessment as a complement to environmental impact assessment: the case of electric vehicles. In: Int J Life Cycle Assess 22 (1), pp. 31–39.

Greening, Lorna; Greene, David L.; Difiglio, Carmen (2000): Energy efficiency and consumption — the rebound effect — a survey. In: Energy Policy 28 (6-7), pp. 389–401.

Häckel, Björn; Pfosser, Stefan; Tränkler, Timm (2017): Explaining the energy efficiency gap - Expected Utility Theory versus Cumulative Prospect Theory. In: Energy Policy 111, pp. 414–426.

Hake, Jürgen-Friedrich; Fischer, Wolfgang; Venghaus, Sandra; Weckenbrock, Christoph (2015): The German Energiewende – History and status quo. In: Energy 92, pp. 532–546.

Hallikas, Jukka; Karvonen, Iris; Pulkkinen, Urho; Virolainen, Veli-Matti; Tuominen, Markku (2004): Risk management processes in supplier networks. In: International Journal of Production Economics 90 (1), pp. 47–58.

Hesse, Tilman; Veit, Bürger (2016): Sektorale Emissionspfade in Deutschland bis 2050 – Gebäudesektor und Stromverbrauch Privathaushalte. Hg. v. Öko-Institut e.V. Berlin. Available online at https://www.oeko.de/oekodoc/2595/2016-603-de.pdf, zuletzt geprüft am 16.04.

Jackson, Jerry (2010): Promoting energy efficiency investments with risk management decision tools. In: Energy Policy 38 (8), pp. 3865–3873.

Jakob, Martin (2006): Marginal costs and co-benefits of energy efficiency investments. In: Energy Policy 34 (2), pp. 172–187.

Kaza, Nikhil (2010): Understanding the spectrum of residential energy consumption: A quantile regression approach. In: Energy Policy 38 (11), pp. 6574–6585.

Klaus, Thomas; Vollmer, Carla; Werner, Kathrin; Lehmann, Harry; Müschen, Klaus (2010): Energieziel 2050. 100% Strom aus erneuerbaren Quellen. Unter Mitarbeit von Thomas Klaus, Carla Vollmer, Kathrin Werner, Harry Lehmann und Klaus Müschen. Hg. v. Umweltbundesamt. Dessau.

Lee, P.; Lam, P.T.I.; Lee, W. L. (2015): Risks in Energy Performance Contracting (EPC) projects. In: Energy and Buildings 92, pp. 116–127.

Li, Yan; Qiu, Yueming; Wang, Yi David (2014): Explaining the contract terms of energy performance contracting in China: The importance of effective financing. In: Energy Economics 45, pp. 401–411.

Liu, Jicheng; Wei, Qiushuang (2018): Risk evaluation of electric vehicle charging infrastructure public-private partnership projects in China using fuzzy TOPSIS. In: Journal of Cleaner Production 189, pp. 211–222.

Loorbach, Derk; Wijsman, Katinka (2013): Business transition management: exploring a new role for business in sustainability transitions. In: Journal of Cleaner Production 45, pp. 20–28.

Ludig, Sylvie; Haller, Markus; Schmid, Eva; Bauer, Nico (2011): Fluctuating renewables in a long-term climate change mitigation strategy. In: Energy (11), pp. 6674–6685.

Masa-Bote, Daniel; Caamaño-Martín, Estefanía (2014): Methodology for estimating building integrated photovoltaics electricity production under shadowing conditions and case study. In: Renewable and Sustainable Energy Reviews 31, pp. 492–500.

Mathew, Paul; Kromer, J.Stephen; Sezgen, Osman; Meyers, Steven (2005): Actuarial pricing of energy efficiency projects: lessons foul and fair. In: Energy Policy 33 (10), pp. 1319–1328.

McDaniel, Patrick; McLaughlin, Stephen (2009): Security and Privacy Challenges in the Smart Grid. In: IEEE Secur. Privacy Mag. 7 (3), pp. 75–77.

Melville; Kraemer; Gurbaxani (2004): Review: Information Technology and Organizational Performance: An Integrative Model of IT Business Value. In: MIS Quarterly 28 (2), pp. 283.

Micale, V.; Deason, J. (2014): Energy Savings Insurance: Phase 2 Analysis Summary. The Global Innovation Lab for Climate Finance.

Mills, Evan (2003): Risk transfer via energy-savings insurance. In: Energy Policy 31 (3), pp. 273–281.

Mills, Evan; Kromer, Steve; Weiss, Gary; Mathew, Paul A. (2006): From volatility to value: analysing and managing financial and performance risk in energy savings projects. In: Energy Policy 34 (2), pp. 188–199.

Muehleisen, Wolfgang; Eder, Gabriele C.; Voronko, Yuliya; Spielberger, Markus; Sonnleitner, Horst; Knoebl, Karl et al. (2018): Outdoor detection and visualization of hailstorm damages of photovoltaic plants. In: Renewable Energy 118, pp. 138–145.

Nestl, U.; Kunz, C. (2014): Studienvergleich: Stromgestehungskosten verschiedener Erzeugungstechnologien. Agentur für erneuerbare Energien. Berlin. Available online at http://www.forschungsradar.de/fileadmin/content/bilder/Vergleichsgrafiken/Stromgestehungskosten_okt2014/AEE_Dossier_Studienvergleich_Stromgestehungskosten_sep14.pdf, zuletzt geprüft am 18.04.2019.

Palensky, Peter; Dietrich, Dietmar (2011): Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads. In: IEEE Trans. Ind. Inf. 7 (3), pp. 381–388.

Patwardhan, Anand Prabhakar; Gomez-Echeverri, Luis; Nakićenović, Nebojša; Johansson, Thomas B. (Hg.) (2012): Global Energy Assessment (GEA). International Institute for Applied Systems Analysis. Cambridge: Cambridge University Press.

Pepermans, G.; Driesen, J.; Haeseldonckx, D.; Belmans, R.; D'haeseleer, W. (2005): Distributed generation: definition, benefits and issues. In: Energy Policy 33 (6), pp. 787–798.

Ramchurn, Sarvapali D.; Vytelingum, Perukrishnen; Rogers, Alex; Jennings, Nicholas R. (2012): Putting the 'smarts' into the smart grid. In: Commun. ACM 55 (4), pp. 86.

Rammerstorfer, Margarethe; Wagner, Christian (2009): Reforming minute reserve policy in Germany: A step towards efficient markets? In: Energy Policy 37 (9), pp. 3513–3519.

Rangaraju, Surendraprabu; Vroey, Laurent de; Messagie, Maarten; Mertens, Jan; van Mierlo, Joeri (2015): Impacts of electricity mix, charging profile, and driving behavior on the emissions performance of battery electric vehicles: A Belgian case study. In: Applied Energy 148, pp. 496–505.

Richter, Mario (2013): Business model innovation for sustainable energy: German utilities and renewable energy. In: Energy Policy 62, pp. 1226–1237.

Rockström, Johan; Gaffney, Owen; Rogelj, Joeri; Meinshausen, Malte; Nakicenovic, Nebojsa; Schellnhuber, Hans Joachim (2017): A roadmap for rapid decarbonization. In: Science (New York, N.Y.) 355 (6331), pp. 1269–1271.

Rogelj, Joeri; den Elzen, Michel; Höhne, Niklas; Fransen, Taryn; Fekete, Hanna; Winkler, Harald et al. (2016): Paris Agreement climate proposals need a boost to keep warming well below 2 °C. In: Nature 534 (7609), pp. 631–639.

Rot, A (2008): IT Risk Assessment: Quantitative and Qualitative Approach. International Association of Engineers; World Congress on Engineering and Computer Science; WCECS. Hong Kong (Lecture notes in engineering and computer science).

Siano, Pierluigi (2014): Demand response and smart grids—A survey. In: Renewable and Sustainable Energy Reviews 30, pp. 461–478.

Sovacool, Benjamin K.; Axsen, Jonn; Kempton, Willett (2017): The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda. In: Annu. Rev. Environ. Resour. 42 (1), pp. 377–406.

Statista (2019): Eigentümerquote in Deutschland im Zeitraum von 1998 bis 2014 nach Bundesländern. Hg. v. Statista. Available online at https://de.statista.com/statistik/daten/studie/155713/umfrage/anteil-der-buerger-mit-wohneigentum-nach-bundesland/, zuletzt geprüft am 04.04.2019.

Swan, Lukas G.; Ugursal, V. Ismet (2009): Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. In: Renewable and Sustainable Energy Reviews 13 (8), pp. 1819–1835.

Tan, Kang Miao; Ramachandaramurthy, Vigna K.; Yong, Jia Ying (2016): Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. In: Renewable and Sustainable Energy Reviews 53, pp. 720–732.

Tucker, Michael (1997): Climate change and the insurance industry: the cost of increased risk and the impetus for action. In: Ecological Economics 22 (2), pp. 85–96.

Tversky, Amos; Kahneman, Daniel (1992): Advances in prospect theory: Cumulative representation of uncertainty. In: J Risk Uncertainty 5 (4), pp. 297–323.

Weeber, Max; Lehmann, Christian; Böhner, Johannes; Steinhilper, Rolf (2017): Augmenting Energy Flexibility in the Factory Environment. In: Procedia CIRP 61, pp. 434–439.

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

Zissis, Dimitrios; Lekkas, Dimitrios (2012): Addressing cloud computing security issues. In: Future Generation Computer Systems 28 (3), pp. 583–592.

II Risk and return management for the heat transition

Chapter II deals with investment risk and return management for the heat transition. Energy efficiency measures and especially energetic retrofitting investments bear great risk, owing to incorrect planning, incorrect implementation, and inappropriate user behavior. Moreover, external risks like volatile energy prices and weather effects also have a major impact on the energy efficiency investment’s profitability. To address these risks, research papers 1-3 provide the scientific basis for the market introduction of energy efficiency insurance products'. In exchange for a premium payment, an energy efficiency insurance guarantees an energy efficiency investment's predefined financial performance, such as minimum energy bill savings or maximum energy bill costs. To achieve this goal, Chapter II provides an approach for pricing energy efficiency insurance premiums and analyzing diversification effects in a portfolio context, as well as providing a model for the individual risk assessment of energy efficiency insurance contracts.

The first research paper, RP1, entitled “*Modeling energy efficiency insurances and energy performance contracts for a quantitative comparison of risk mitigation potential*,” in Section II.1 introduces a heating energy forecast model, which is the basis for the fair premium calculation of energy efficiency insurance products'. On this basis, the study uses different statistical risk measures to compare the different contract designs' risk mitigation potential.

The second research paper, RP2, entitled “*Managing the risks of energy efficiency insurances in a portfolio context: an actuarial diversification approach*,” in Section II.2 provides a quantitative modeling approach for analyzing the diversification effects between energy efficiency insurances, property insurances and weather derivatives in a portfolio context. Insurance companies can use RP2’s modelling approach to calculate regulatory equity capital under Solvency II.

The third research paper, RP3, entitled “*A D-vine copula quantile regression approach for the prediction of residential heating energy consumption based on historical data*,” in Section II.3 provides a quantile-based prediction model of residential heating energy consumption in order to assess the energetic retrofitting investments' household-specific risks. If the predicted risk is high, an insurance company can charge higher premiums or exclude the corresponding customers. Furthermore, RP3 analyzes the savings potential of different energetic retrofitting bundles and identifies suitable retrofitting paths.

II.1 Research paper 1: “Modeling energy efficiency insurances and energy performance contracts for a quantitative comparison of risk mitigation potential”

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In:	*Energy Economics, 80, p. 842-859*

Abstract: *Financial risk mitigation via Energy Performance Contracting or Energy Efficiency Insurances may overcome individual barriers for energy efficiency investments. However, while the financial industry, and especially insurance companies, may have compelling reasons to get involved in energy efficiency investments, the research on and real-world applications of risk transfer contracts for private decision-makers are scarce. Thus, this study quantitatively compares the risk mitigation potential of risk transfer contracts based on a comprehensive energy bill savings forecast model comprising stochastic processes for weather, commodity prices, and technological energy efficiency performance. The model is fitted with a unique dataset for German residential buildings. Our findings indicate that risk transfer contracts positively affect individual decision-makers' willingness to invest in energy efficiency. Generally, we find Energy Performance Contracts to be superior in most scenarios when transaction costs are not considered. However, insurance companies may benefit from diversification effects and by ceding risks to global capital markets and reinsurance companies.*

II.2 Research paper 2: “Managing the risks of energy efficiency insurances in a portfolio context: an actuarial diversification approach”

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In: *International Review of Financial Analysis, 68, Article 101313*

Abstract: *To achieve ambitious international climate goals, an increase of energy efficiency investments is necessary and, thus, a growing market potential arises. Concomitantly, the relevance of managing the risk of financing and insuring energy efficiency measures increases continuously. Energy Efficiency Insurances encourage investors by guaranteeing a predefined energy efficiency performance. However, literature on quantitative analysis of pricing and diversification effects of such novel insurance solutions is scarce. This paper provides a first approach for the analysis of diversification potential on three levels: collective risk diversification, cross product line diversification, and financial hedging. Based on an extensive real-world data set for German residential buildings, the analysis reveals that underwriting different Energy Efficiency Insurance types and constructing Markowitz Minimum Variance Portfolios halves overall risk in terms of standard deviation. We evince that Energy Efficiency Insurances can diversify property insurance portfolios and reduce regulatory capital for insurers under Solvency II constraints. Moreover, we show that Energy Efficiency Insurances potentially supersede financial market instruments such as weather derivatives in diversifying property insurance portfolios. In summary, these three levels of diversification effects constitute an additional benefit for the introduction of Energy Efficiency Insurances and may positively impact their market development*.

II.3 Research paper 3: “A D-vine copula quantile regression approach for the prediction of residential heating energy consumption based on historical data”

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In:	*Applied Energy, 233-234, p. 691-708*

Abstract: *Energetic retrofitting of residential buildings is poised to play an important role in the achievement of ambitious global climate targets. A prerequisite for purposeful policy making and private investments is the accurate prediction of energy consumption. Building energy models are mostly based on engineering methods quantifying theoretical energy consumption. However, a performance gap between predicted and actual consumption has been identified in literature. Data-driven methods using historical data can potentially overcome this issue. The D-vine copula-based quantile regression model used in this study achieved very good fitting results based on a representative data set comprising 25,000 German households. The findings suggest that quantile regression increases transparency by analyzing the entire distribution of heating energy consumption for individual building characteristics. More specifically, the analyses reveal the following exemplary insights. First, for different levels of energy efficiency, the rebound effect exhibits cyclical behavior and significantly varies across quantiles. Second, very energy-conscious and energy-wasteful households are prone to more extreme rebound effects. Third, with regards to the performance gap, heating energy demand of inefficient buildings is systematically underestimated, while it is overestimated for efficient buildings.*

III Risk and return management for business models at the interface of the energy, heat, and transport transition

III.1 Research paper 4: “Ein Entscheidungsunterstützungssystem[1] zur ökonomischen Bewertung von Mieterstrom auf Basis der Clusteranalyse”

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In:	*Tagungsband der 14. Internationalen Tagung Wirtschaftsinformatik, Siegen, Germany February 2019, p. 1478-1492*

Abstract: *Für den Erfolg der Energiewende spielt die dezentrale Stromerzeugung eine entscheidende Rolle. Aus diesem Grund wurde das Geschäftsmodell Mieterstrom entwickelt, welches sich über die Erzeugung und Lieferung von Strom in direktem räumlichem Zusammenhang definiert. Dabei soll durch den direkten Verkauf von Strom an Mieter ein höherer Gewinn erzielt werden, im Vergleich zur klassischen Stromeinspeisung ins Netz. Zur Förderung von Mieterstrom in Deutschland wurde 2017 von politischer Seite ein umfassendes Förderprogramm beschlossen und somit die Rahmenbedingungen deutlich verbessert. Basierend auf Smart Meter Daten wird in diesem Beitrag deshalb ein Entscheidungsunterstützungsmodell zur Investitionsbewertung von Mieterstrommodellen entwickelt und evaluiert. Dafür wird in einem ersten Schritt eine Clusteranalyse durchgeführt, um anschließend auf Basis der durchschnittlichen Stromverbrauchsprofile der Cluster sowie bedingter Wahrscheinlichkeiten die Rentabilität eines Mieterstrommodells vorherzusagen. Die in einer Fallstudie evaluierten Investitionen weisen eine Amortisationszeit von 8 bis 14 Jahren sowie eine CO2-Einsparung von über 60% auf.*

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[1] Der in RP4 formulierte Anspruch, dass ein Entscheidungsunterstützungssystem für Mieterstrom entwickelt wird, muss nachträglich abgeschwächt werden, da im Paper lediglich Teilaspekte eines Entscheidungsunterstützungssystem adressiert werden (z.B. fehlt die Preisentwicklung der Energieträger). Da RP4 zur Drucklegung in der vorliegenden Fassung bereits veröffentlicht wurde, wird dieser Aspekt in Abschnitt III.2 diskutiert.

III.2 Discussion and practical implications of research paper 4

Das folgende Kapitel adressiert die im Rahmen der Begutachtung aufgekommenen Kommentare der Gutachter und soll den Anspruch des Papers „Ein Entscheidungsunterstützungssystem zur ökonomischen Bewertung von Mieterstrom auf Basis der Clusteranalyse“ abschwächen. Ergänzend zu den im Paper entwickelten Teilmodulen eines Entscheidungsunterstützungssystems werden dafür relevante Rahmenbedingungen des Mieterstroms, wie Kostenstrukturen oder aktuelle Förderbedingungen, ergänzt, um somit die praktische Anwendbarkeit zu erhöhen.

III.2.1 Herleitung der Kosten- und Ertragsstruktur zur praktischen Anwendung des Modells

Die Modellierung der initialen Investitionskosten sowie der laufenden Kosten spielen eine wichtige Rolle bei der Investitionsbewertung von Mieterstrom. Nach Paschka (2017) lassen sich die initialen Investitionskosten in sechs Dimensionen einteilen: das Anlagen- und Zählerkonzept inkl. Smart Meter, die Abrechnungssoftware, das Blockheizkraftwerk (BHKW), ggf. der Brennwertkessel für Spitzenlasten, der Pufferspeicher und die PV-Anlage. Je nach Dimensionierung der Anlage variieren diese Kosten regional zum Teil stark, wobei die Technik zur Erzeugung von Strom und Wärme (PV-Anlage, BHKW und Brennwertkessel) in der Regel einen gemeinsamen Anteil von mindestens 80% der Investitionskosten ausmacht (BKI 2017). Die in dem Paper angenommenen Investitionskosten I_0 von $50.000€$ für das Szenario 1 mit einer $3kW$ Brennstoffzelle und einer $10kWp$ PV-Anlage, orientieren sich dabei an den marktüblichen Investitionskosten und beinhalten bereits Fördermittel[2]. Die genannten Skaleneffekte i.H.v. 10% pro kW-Leistung für das Szenario 2 in RP4 (Quartierslösung) wurden als Annahme getroffen.

Die laufenden Kosten K_t lassen sich in verbrauchsgebundenen und betriebsgebundenen Kosten aufteilen (Paschka 2017). Die verbrauchsgebundenen Kosten für den Direktverbrauch setzen sich aus dem Erdgasbezug sowie der zu zahlenden EEG-Umlage zusammen[3]. Da davon ausgegangen werden kann, dass eine Brennstoffzelle durchgängig betrieben wird, ergeben

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[2] Es wurde für die PV-Anlage ein Preis pro kWp i.H.v. 1.340€ zugrunde gelegt (Solaranlagenportal 2018), für zwei Brennstoffzellenmodule BLUEGen der Firma SolidPower jeweils 26.000€ Anschaffungskosten angenommen (auf Basis eines eingeholten Angebots), abzüglich eines Förderbetrags i.H.v. 19.200€ als Grundförderung (KfW 2018) sowie 3.800€ als Annahme für in Summe das Anlagen & Zählerkonzept, die Abrechnungssoftware sowie den Pufferspeicher aufgeschlagen.

[3] Für das Publikationsjahr 2018 waren dies für Gas ca. 4 Cent pro kWh (Statista 2020) und für die EEG-Umlage ca. 7 Cent pro kWh (Bundesnetzagentur 2017).

sich für das Jahr 2018 für eine Brennstoffzelle mit $3kW$ bzw. $22{,}5kW$, bei einem Wirkungsgrad von 60%, Kosten i.H.v. ca. $1.750€/a$ und $13.125€/a$ für den Erdgasbezug. Die EEG-Umlage wurde in RP4 zur Vereinfachung und aus Platzgründen direkt mit dem erzielten Strompreis P_t^{MS} verrechnet und wird in der nachfolgenden Herleitung des Strompreises nochmals thematisiert.

Die betriebsgebundenen Kosten setzen sich aus den Wartungskosten des BHKW mit durchschnittlich $3{,}15$ Cent pro kWh (Paschka 2017), den Kosten für den Messstellenbetrieb, welche je nach Anzahl der Haushaltsanschlüsse stark variieren, den Kosten für die Abrechnung der Stromlieferung an die Mieter sowie ggf. einer Versicherungsprämie zusammen. In Tabelle III.2-1 werden die in RP4 als konstant angenommenen Kosten K_t nochmals aufgegliedert, wobei die Abrechnungskosten und die Kosten für den Messstellenbetrieb nach eigenen Recherchen festgelegt wurden.

Table III.2-1: Zusammensetzung der jährlichen Kosten für die zwei Szenarien aus RP4

Kostenart	Szenario 1 (3kW)	Szenario 2 (22,5kW)
Erdgasbezug	1.750 €/a	13.125 €/a
Wartungskosten	850 €/a	6.375 €/a
Abrechnungskosten Mieter	250 €/a	500 €/a
Messstellenbetrieb	150 €/a	250 €/a
Jährliche Gesamtkosten (K_t)	**3.000 €/a**	**20.250 €/a**

Neben der möglichst adäquaten Vorhersage der erzeugten Strommenge und des Verbrauchsprofils der Mieter, spielt der gewählte Mieterstrompreis P_t^{MS} eine wichtige Rolle bei der Investitionsbewertung. Dies wurde in RP4 stark vereinfacht, ohne die einzelnen Komponenten separat auszuweisen. Der Grenzwert für den Endkundenpreis für Mieterstrom beträgt in Deutschland ca. 29 Cent pro kWh, da dieser den regional geltenden Grundversorgungstarif (ca. 32 Cent pro kWh[4]) um mindestens 10% unterschreiten muss (vgl. § 42a Abs. 4 S. 1 EnWG). In der Praxis ergibt sich der Mieterstrompreis P_t^{MS} aus dem Endkundenpreis, zuzüglich einem Mieterstromzuschuss je nach Anlagendimensionierung, abzüglich der oben bereits genannten EEG-Umlage sowie einem Preisnachlass für die beteiligten Mieter als Anreizmechanismus. Darüber hinaus können Betreiber einen Zuschuss aufgrund der Vermeidung von Netzentgelten und der Energiesteuereinsparung beantragen.

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[4] https://www.sw-augsburg.de/energie/swa-strom/swa-strom-basis/, abgerufen am 16.08.2019

Table III.2-2: Zusammensetzung des Mieterstrompreises aus RP4

Preiskomponente	Betrag
Grenzwert Endkundenpreis Strom pro kWh	+29 Cent
Mieterstromzuschuss pro kWh	+3 Cent (BMWi 2017)
Vermeidung von Netzentgelten und der Energiesteuereinsparung pro kWh	+1 Cent[5]
EEG-Umlage	-7 Cent (Bundesnetzagentur 2017)
Preisnachlass für Mieter	-1 Cent
Mieterstrompreis P_t^{MS}	**25 Cent**

In Tabelle III.2-2 ist die Herleitung des verwendeten Mieterstrompreis P_t^{MS} in RP4 dargestellt, welcher mit einem Preisnachlass i.H.v. lediglich 1 $Cent/kWh$ höher ausfällt als üblich. Hier lassen sich in der Praxis durchaus größere Preisnachlässe beobachten, um möglichst viele Mieter für den Mieterstrom zu gewinnen.

III.2.2 Diskussion weiterer Risikoaspekte und Auswirkung des Klimaschutzprogramms 2030 der Bundesregierung

In RP4 wurde aus einer Risikoperspektive insbesondere auf die Erzeugungsprofile und auf das Verbrauchsverhalten der Nutzer eingegangen. Jedoch müssen für eine umfassende Risikobewertung einer Mieterstrominvestition weitere Risiken betrachtet werden. Bezüglich des Nutzerverhaltens in verschiedenen Lebensphasen (dies wurde in RP4 als konstant angenommen) zeigten O'Neill und Chen (2002), dass mit zunehmendem Alter ein linear ansteigender Energiebedarf nachgewiesen werden kann. Zusätzlich merkten Martínez-Espiñeira et al. (2014) an, dass bestimmte Lebensveränderungen, wie z.B. die Geburt eines Kindes, den Stromverbrauch signifikant verändern können. Die in RP4 auf Seite 187 genannte Erweiterungsidee, ein Teilmodell zu Modellierung und Fortschreibung des Nutzerverhaltens zu ergänzen, sollte diese linearen Zunahmen mit steigendem Alter sowie der Möglichkeit von sprunghaften Veränderungen beim Stromverbrauch berücksichtigen.

Die bundesweite Vermieterbefragung des Zentralverbands der Deutschen Haus-, Wohnungs- und Grundeigentümer e. V. im Jahr 2019 zeigte, dass die durchschnittliche Mietdauer in Deutschland bei 9,6 Jahren liegt. Lediglich bei 11,9 % der erfassten Mietverhältnisse beträgt die Mietdauer über 20 Jahre (Haus & Grund 2019). Das bedeutet für den Mieterstrom, dass das initial unterstellte Verbrauchsprofil sich schon nach wenigen Jahren deutlich ändern kann.

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[5] Vgl. § 53 EnergieStG (Steuerentlastung für die Stromerzeugung und für Einsatz in KWK-Anlagen)

Vor dem Hintergrund der langen Betrachtungszeiträume muss daher mit einem mehrfachen Mieterwechsel pro Wohneinheit gerechnet werden. Zusätzlich besteht rechtlich kein Zwang, dass die zukünftigen Mietparteien den Mieterstrom abnehmen müssen, was ggf. zu einem erheblichen Rückgang des Ertrags führt und insbesondere bei kleineren Anlagen besonders zu berücksichtigen ist. Es kann davon ausgegangen werden, dass je größer der Preisnachlass für die Mieter ausfällt, desto größer ist die Wahrscheinlichkeit, dass die Mieter den Mieterstrom abnehmen. Da in RP4 lediglich ein sehr geringer Preisnachlass unterstellt wurde, ist das Risiko der unsicheren Stromabnahme für die betrachteten Szenarien als hoch einzuschätzen. Ebenfalls müssten Kosten bzw. Verdienstausfälle im Zuge einer Zahlungsunfähigkeit eines Mieters berücksichtigt werden. Ein weiteres Risiko stellt die unsichere Entwicklung der betriebsgebundenen Kosten dar. Die Wartungs- und Abrechnungskosten bestehen zu einem großen Teil aus Personalkosten, welche in den letzten Jahren in Deutschland im Schnitt um ca. 2% pro Jahr gestiegen sind (Voigtländer und Sagner 2020). Geht man davon aus, dass sich die Preisentwicklung bei benötigten Ersatzteilen ähnlich der Preisentwicklung von Ersatzteilen der Automobilindustrie entwickelt, kann hier ein Zuwachs von ca. 4% pro Jahr angenommen werden (Insurance Europe & GDV 2020). Als mögliche Erweiterung des Modells könnte somit bei den betriebsgebundenen Kosten eine Preissteigerung von jährlich zwischen 2% bis 4% angenommen werden.

Wie jedoch in Tabelle III.2-1 dargestellt, stellen die verbrauchsgebundenen Kosten für den Erdgasbezug den größten Anteil der Kosten dar. Insbesondere in RP1 und RP2 (siehe Kapitel II) wurden die Preisrisiken von Öl und Gas diskutiert sowie Modellierungsmöglichkeiten aufgezeigt. Im Zuge einer Monte Carlo Simulation könnten zukünftige Gaspreisverläufe simuliert und bei Bedarf weitere Risikokennzahlen (z.B. der Value at Risk) für die Analyse von Mieterstrom verwendet werden. Ein ausführlicher Vergleich von stochastischen Modellen für die Modellierung von Gaspreisen wurde von Chan und Grant (2016) durchgeführt. Die Autoren empfehlen ein sogenanntes Moving Average Stochastic Volatility Model zur Modellierung von Gaspreisen, welches auch in RP1 und RP2 verwendet wurde. Ergänzend entwickelten Qin et al. (2019) ein Modell zur Simulation von Strompreisen, welches zur Modellierung von Preisrisiken auf der Ertragsseite von Mieterstrom verwendet werden kann.

Vor dem Hintergrund der in RP4 nicht abgebildeten Preisrisiken für Strom und Gas, stellt sich insbesondere die Frage nach einem besonders schwerwiegenden Risikoszenario, wenn Mieter bei einer Verbilligung von Strom und einer Verteuerung von Gas geschlossen ihr

Bezugswahlrecht nutzen und den Strom statt beim Vermieter bei einem günstigeren Anbieter beziehen. Insbesondere das Klimaschutzprogramm 2030 der Bundesregierung und der in diesem Zuge eingeführten CO_2-Steuer, lässt dieses Szenario wahrscheinlicher werden. So soll bis 2025 schrittweise eine CO_2-Steuer i.H.v. 35 Euro pro Tonne CO_2 eingeführt werden (Die Bundesregierung 2019), wodurch sich der Gaspreis um ca. $0{,}75\ Cent/kWh$ erhöhen würde (Frondel 2019) und somit die jährlichen Kosten in beiden Mieterstrom-Szenarien von RP4 um ca. 10% steigen lässt. Nach 2025 sind zusätzlich weitere Steigerungen der CO_2-Steuer zu erwarten, sodass sich dieser Trend wohl über den gesamten Betrachtungszeitraum fortsetzen wird und somit zu berücksichtigen wäre (z.B. über die Modellierung einer konstanten Wachstumsrate des Gaspreises). Die zur Entlastung von Bürgern und Wirtschaft geplante Senkung der EEG-Umlage zur Verteilung der Einnahmen aus der CO_2-Steuer wird keinen wirtschaftlichen Effekt auf Mieterstrom haben, da diese Umlage lediglich als durchlaufender Posten zu betrachten ist. Inwieweit jedoch die Rahmenbedingungen und Fördermöglichkeiten von Mieterstrom zukünftig politisch gestärkt werden, bleibt abzuwarten, denn „weitere Akzeptanzmaßnahmen werden geprüft, zum Beispiel die Verbesserung der Rahmenbedingungen beim Mieterstrom“ (Die Bundesregierung 2019, S. 38). Sollte sich die Förderlandschaft in den kommenden Jahren für Mieterstrom nicht verbessern, können die in RP 4 genannten Amortisationszeiten von 8 bis 14 Jahren wahrscheinlich nicht erreicht werden. Es muss davon ausgegangen werden, dass sich ohne politisches Handeln Mieterstrom zukünftig vielfach ökonomisch nicht rechnet. Die in diesem Kapitel aufgezeigten, wahrscheinlich negativen Entwicklungen auf der Kostenseite müssten ggf. also zu einem Großteil von der Politik übernommen werden, um die ökonomischen Anreize für Mieterstrom sicherzustellen. Zwar kann davon ausgegangen werden, dass zum Teil die initialen Investitionskosten für ein BHKW oder eine PV-Anlage weiter sinken werden, jedoch wahrscheinlich nicht in dem notwendigen Ausmaß. Eine CO_2-Steuerbefreiung von Mieterstromanlagen wäre hier wohl die pragmatischste Lösung. Dieses Beispiel zeigt anhand von Mieterstrom wie komplex Klimapolitik ist und legt somit eine vermeintliche Schwäche des Klimaschutzplans 2030 offen.

III.2.3 Literatur

Paschka, D.: Wirtschaftlichkeit von Mieterstrom. In: Behr, I., Großklos, M. (eds.) Praxishandbuch Mieterstrom, pp. 125–139. Springer Fachmedien, Wiesbaden (2017)

BKI-Baukosteninformationszentrum Deutscher Architektenkammern, B.-B.D. (BKI): BKI Baupreise kompakt 2018 - Neu- und Altbau. Statistische Baupreise für Positionen mit Kurztexten. BKI, Stuttgart (2017)

Solaranlagenportal: Photovoltaik Kosten Eigenheime - der Überblick. Hamburg. Online verfügbar unter https://www.https://www.solaranlagen-portal.com/photovoltaik/kosten, zuletzt geprüft am 04.04.2020. (2018)

Kreditanstalt für Wiederaufbau (KfW): Energieeffizient Bauen und Sanieren – Zuschuss Brennstoffzelle. Frankfurt. Online verfügbar unter https://www.kfw.de/PDF/Download-Center/F%C3%B6rderprogramme-(Inlandsf%C3%B6rderung)/PDF-Dokumente/Arbeitshilfen-Pr%C3%A4sentationen/Pr%C3%A4sentationen/Energieeffizient-Bauen-und-Sanieren-Zuschuss-Brennstoffzelle-(433).pdf, zuletzt geprüft am 04.04.2020. (2018)

Statista: Gaspreise* für Gewerbe- und Industriekunden in Deutschland in den Jahren 2009 bis 2019. Hamburg. Online verfügbar unter https://de.statista.com/statistik/daten/studie/168528/umfrage/gaspreise-fuer-gewerbe--und-industriekunden-seit-2006/, zuletzt geprüft am 04.04.2020. (2020)

Bundesnetzagentur: EEG-Umlage 2018. Bonn. Online verfügbar unter https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Presse/Pressemitteilungen/2017/16102017_EEG-Umlage.pdf?__blob=publicationFile&v=2, zuletzt geprüft am 04.04.2020. (2017)

BMWi: Eckpunktepapier Mieterstrom. Berlin. Online verfügbar unter https://www.bmwi.de/Redaktion/DE/Downloads/E/eckpunkte-mieterstrom.pdf?__blob=publicationFile&v=10, zuletzt geprüft am 04.04.2020. (2017)

O'Neill, B. C., & Chen, B. S.: Demographic determinants of household energy use in the United States. Population and development review 28, 53-88 (2002)

Martínez-Espiñeira, R., García-Valiñas, M. A., & Nauges, C.: Households' pro-environmental habits and investments in water and energy consumption: Determinants and relationships. Journal of environmental management 133, 174-183 (2014)

Voigtländer, M., Sagner, P.: Entwicklung von Löhnen und Mieten: Dreigeteiltes Deutschland (No. 4/2020). IW-Kurzbericht (2020)

Insurance Europe & GDV: Spare Parts Price Survey, Preise für Auto-Ersatzteile steigen kräftig weiter. Online verfügbar unter https://www.gdv.de/de/medien/aktuell/preise-fuer-auto-ersatzteile-steigen-kraeftig-weiter-51338, zuletzt geprüft am 04.04.2020. (2020)

Chan, J.C.C., Grant, A.L.: Modeling energy price dynamics: GARCH versus stochastic volatility. Energy Economics 54, 182–189. (2016)

Qin, Q., Xie, K., He, H., Li, L., Chu, X., Wei, Y. M., & Wu, T.: An effective and robust decomposition-ensemble energy price forecasting paradigm with local linear prediction. Energy Economics 83, 402-414 (2019)

Haus & Grund - Zentralverbands der Deutschen Haus-, Wohnungs- und Grundeigentümer e. V.: Haus & Grund Vermieterbefragung 2019 Deutschland. Online verfügbar unter https://www.hausundgrund.de/sites/default/files/downloads/vermieterbefragungdeutschland2019.pdf, zuletzt geprüft am 04.04.2020. (2019)

Frondel, M.: CO2-Bepreisung in den nicht in den Emissionshandel integrierten Sektoren: Optionen für eine sozial ausgewogene Ausgestaltung (No. 130). RWI Materialien. (2019)

Die Bundesregierung: Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050. Berlin. Online verfügbar unter https://www.bundesregierung.de/resource/blob/975226/1679914/e01d6bd855f09bf05cf7498e06d0a3ff/2019-10-09-klima-massnahmen-data.pdf?download=1, zuletzt geprüft am 04.04.2020. (2019)

IV IT risk management as prerequisite for low-carbon transitions

IV.1 Research paper 5: "Reducing the pain of the inevitable: assisting IT project Managers in performing risk management"

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Abstract: *An organization's IT landscape is seldom static due to changes in applications, data, or infrastructure. These mostly project-related changes alter the organization's risks. Effective IT risk management requires information on these changes to manage risks. "Traditional" methods for risk management are challenged by a fast-developing IT and the lack of qualified experience. To support project and risk managers in IT risk management, we apply method engineering to develop an integrated method that connects knowledge on threats, actors, vulnerabilities, and mitigation measures with risk-relevant project characteristics to identify, quantify, and mitigate a project's risks. We evaluate our method in a single case study by deploying a software prototype at a globally acting manufacturer of construction and demolition tools with over 25.000 employees. Our evaluation shows that the proposed method has the potential to improve IT risk management regarding standardization and efficiency, while communication and training of end users are crucial.*

V Results and future research

In this chapter, the author presents the doctoral thesis's key findings (Section V.1), the potential future research areas (Section V.2) and also a short conclusion (Section V.3).

V.1 Results

The main objective of this doctoral thesis is to contribute to low-carbon transition risk and return management. Thereby, this thesis focuses on the heat transition and business models at the interface of the energy, heat, and transport transition. After motivating the importance of risk and return management to achieve international climate goals, this doctoral thesis presents five research papers that develop risk and return management approaches for selected challenges. Next, this chapter presents the research papers' key findings. Finally, the author discusses future research opportunities and provides a short conclusion.

V.1.1 Results of Chapter II: Risk and return management for the heat transition

Chapter II focuses on energy efficiency insurances that address energetic retrofitting investment risks. In this context, the chapter provides statistical methods for the investment evaluation and, in particular, the associated risks. Research paper (RP) 1 discusses the fair insurance premium calculation of energy efficiency insurance products', RP2 evaluates energy efficiency insurance products’ diversification effects in the context of regulatory requirements (Solvency II), and RP3 presents a quantile regression approach for the customer-specific risk and return analysis of energetic retrofitting investments.

- In Section II.1, research paper RP1 transfers Mills’s (2003) idea of a financial risk transfer instrument for managing energy efficiency risks (energy efficiency insurance) to the energetic retrofitting field for one-family and two-family homes. Thereby, RP1 aims at introducing a data-based pricing approach for energy efficiency insurance products and comparing different contract designs (Objective II.1). The introduced premium pricing approach uses a quantitative model that predicts the distribution of energy bill savings after energetic retrofitting based on real-world data for Germany. By applying a postulated equivalence principle, RP1 aims at making different contract designs fit for comparison in order to analyze their individual risk mitigation potential. The empirical analysis reveals compelling evidence that risk transfer instruments positively affect individual decision-maker's willingness to invest in energetic retrofitting. An exemplary energetic retrofitting case study (retrofit windows, walls, and roof insulation, as well as heating system) shows that an energy efficiency insurance product's annual fair premium amounts to approximately 10% of the guaranteed savings (annual fair premium of about 160€ to guarantee annual energy bill savings of 1,600€). Furthermore, following Prospect Theory, the results indicate that energy efficiency insurance products must insure levels slightly below the expected energy bill savings to maximize the customer’s utility. Insuring a predefined energy bill cost level (e.g., energy flat rate) and not the energy bill savings, induces adverse effects and thus is not beneficial for private households. For example, the Value at Risk of the net present saving of the considered energetic retrofitting investment with an insured energy bill cost level worsens by 20%. RP1 also emphasizes the transaction costs' relevance for the different contract designs' attractiveness. Finally, the RP1's results confirm that introducing energy efficiency insurance to private customers could stimulate energetic retrofitting and thus support Germany's heat transition targets.

- In Section II.2, research paper RP2 studies insurance portfolios that include energy efficiency insurances. By analyzing the diversification effects in portfolios that contain energy efficiency insurances, RP2 tries to reduce the insurance companies' regulatory costs (Objective II.2). RP2, therefore, examines the diversification effects on three stepwise levels: (1) collective risk diversification in homogeneous energy efficiency insurance portfolios, (2) cross-product line diversification between different insurance types, and (3) diversification via hedging with financial derivatives (Gatzert and Wesker 2012). The energy efficiency insurance portfolio’s risk decreases sharply if the portfolio contains energy efficiency insurances that insure different risk events (e.g., one contract type guarantees energy bill savings and the other contract type guarantees energy bill costs). More specifically, combining different types of energy efficiency insurances reduces the portfolios’ standard deviation or Value at Risk by up to 50% compared to stand-alone risks. Cross-product line diversification can further reduce the remaining risk by approximately 20%, as RP2 shows for the example of portfolios combining energy efficiency insurances and car insurances. However, financial hedging via weather derivatives does not have further notable diversification effects. Instead, RP2 emphasizes that energy efficiency insurance could replace weather derivatives as an insurance portfolio's financial hedging instrument if the insurer dispenses with the weather derivative’s positive properties, such as short-term liquidity. The conducted sensitivity analysis states that the observed diversification effects are robust and notably high for multiple scenarios. From a Solvency II perspective, the energy efficiency insurance portfolios' collective risk and product line diversification reduces economic capital requirements.

- In Section II.3, research paper RP3 introduces a D-vine copula-based quantile regression model (Kraus and Czado 2017) for the prediction of residential heating consumption. This regression model aims at improving the risk assessment of individual energy efficiency insurance contracts (Objective II.3). Therefore, RP3 calculates the expected household-specific rebound effect, which academics define as the increase of the consumption level (e.g., higher indoor temperature, heating more living space) after the implementation of energy efficiency measures, thereby characterizing the deviation from an ex ante predicted energy consumption value (Greening et al. 2000). Based on real-world data comprising 25,000 one-family to two-family homes in Germany, the estimated copula model includes six building characteristics (building age, energy type, roof insulation, wall insulation, glazing, heating system age class) and achieves very good fitting results with an average coverage error of between only 0.0231 and 0.0184 for the quantiles tested. In accordance with the literature, the copula model reveals that heating energy consumptions exhibit a huge variance, even for buildings with the similar characteristics, and motivates the potential of energy efficiency insurances. RP3 reveals that the rebound effect varies greatly for different energetic retrofitting measures. For example, the results emphasize that roof insulation leads to particularly large energy bill savings for energy-conscious households, whereas energy-wasteful households realize almost no energy bill savings in this case. With regard to energy efficiency insurances, the high rebound effects expected for the individual energetic retrofitting measures or specific bundles might lead to contract exclusions. For instance, if an isolated retrofitting measure's expected rebound effect is very high and only small energy bill savings are thus expected, an insurer would possibly not issue an insurance contract. Moreover, RP3 shows that very energy-conscious and energy-wasteful households are prone to more extreme rebound effects and, as a result, the insurer will, therefore, not select these households favorably for energy efficiency insurances. Practitioners can also use the presented forecast model for prioritizing and selecting energetic retrofitting bundles. For example, the energetic retrofitting of all building components at the same time shows, on average, lower rebound effects than partial energetic retrofitting. Finally, RP3 demonstrates that engineering methods usually underestimate the inefficient buildings' energy demand, whereas efficient buildings are overestimated.

V.1.2 Results of Chapter III: Risk and return management for business models at the interface of the energy, heat, and transport transition

Chapter III provides parts of a decision support system for the landlord-to-tenant electricity supply model as the business model at the energy, heat, and transport transition interface. Research paper RP4 in Section III.1 therefore addresses relevant aspects of the investment evaluation of landlord-to-tenant electricity supply models. The model's economic attractiveness depends on various risks, such as the occupants' behavior and photovoltaic systems’ performance. However, various tax concessions and subsidies encourage landlords to sell as much of the electricity they produce as possible to their tenants, because the landlords can more or less double their income compared to the normal feed-in tariff. For the landlords, the tenants’ own energy consumption becomes a decisive performance indicator and determines the investment’s profitability (especially the tenants’ own consumption factor defined as a percentage of self-used energy). RP4, therefore, provides a data-based approach that considers the individual tenants’ load profiles, which can be used for the evaluation of landlord-to-tenant electricity supply investments (Objective III.1). The presented parts of a decision support system bases on a cluster analysis to determine different electricity consumption profiles and Bayes classifiers in order to predict the tenants’ load profiles, depending on their demographic and socioeconomic characteristics. To evaluate the developed approach, RP4 assesses two landlord-to-tenant electricity supply investments based on real-world data (a residential area with thirty households and an apartment building with four households). RP4 assumes that a fuel cell will be installed for the basic energy supply and that a photovoltaic system will be installed for an energy supply throughout the day. The smaller investment example (four households) exhibits a 65% yearly own consumption factor, whereas the residential area shows a 76% yearly own consumption factor, which makes the residential area’s landlord-to tenant electricity supply model more attractive. Evaluating the tenants' predicted monthly own consumption factor shows an absolute error of between 2.5% and 3.5%, whereby the error decreases as the number of tenants increase. The case studies' results show that landlord-to-tenant electricity supply models exhibit a payback period of between eight to 14 years, depending on the installed energy capacity. If, however, the gas price should rise more than the electricity price during the next few years, the payback period increases significantly. In this case, only a photovoltaic system without fuel cells should be installed. Furthermore, the analyzed investment scenarios show CO_2 savings that exceed 60% compared to Germany's average energy mix.

V.1.3 Results of Chapter IV: IT risk management as prerequisite for low-carbon transitions

Chapter IV emphasizes IT risks which also challenge secure business model and solution development in the low-carbon transition context. Especially risk factors like cyber security, system reliability, compliance, and natural disasters must be addressed in detail to fulfill the energy, heat, and transport networks' strict requirements (Chapman et al. 2013). RP5 therefore provides a general, clearly defined IT risk management method. This method can structure and guide the developing process of solutions for low-carbon transitions from a risk perspective (Objective IV.1). To support the project and risk managers in IT risk management, RP5 applies method engineering (Denner et al. 2018) to develop an integrated method that connects risk and mitigation measure knowledge to risk-relevant project characteristics in order to identify, quantify, and mitigate risks of IT solutions. To develop a suitable method, RP5 states three major design objectives: 1) enhance risk management quality by standardizing identification and quantification, 2) make IT risk management accessible to non-experts, and 3) support project managers throughout the whole project management process. The presented method consists of three main activities, which can be traced back to risk identification, quantification, and mitigation selection. RP5 describes each activity using the following five elements: i) introducing the activity, ii) specifying the used technique, iii) introducing the required roles, iv) describing the mathematical engine, and v) defining the activity’s output. A single case study at a global tool manufacturer prototypically instantiates this method and the author uses the case study to evaluate the method. For developing and testing the method, RP5 considers 41 IT projects. The tool manufacturer's eight participants confirmed that the time-consuming risk analysis task is much more accessible with regard to effectiveness and efficiency after introducing the new method. Certain participants mentioned that the standardized risk assessment based on consistent scales provides the biggest benefit. On the process integration level, the participants confirmed that the risk assessment quality improved significantly. They also highlighted the fact, that the developed tool provides an end-to-end support for a secure development process and helps to collect and structure risk-relevant information in all development phases. However, the participants stated that training the method’s end users is crucially important and suggested to enhance the tool by automatically created presentations and reporting functions. In sum, RP5 shows that the proposed method has the potential to improve IT risk management and could therefore be used to develop secure and solid digital solutions in the low-carbon transition field.

V.2 Future research

In the following, the author highlights potential aspects for future research for each chapter of this thesis.

V.2.1 Future research identified in Chapter II: Risk and return management for the heat transition

The limitations of RP1 that provide opportunities for future research are:

- The developed energy efficiency insurance pricing approach does not elaborate on information asymmetries that result in moral hazard and adverse selection (Akerlof 1970; Rothschild and Stiglitz 1976). RP3's quantile regression approach can potentially contribute to overcome adverse selection by identifying and not issuing insurance contracts or charging higher premiums for high-risk households, as is customary in other insurance sectors (e.g., life insurance products exclude extreme sportsmen). In the future, smart meters, which are becoming more and more common in the smart home context, will possibly also detect moral hazard.
- Furthermore, RP1’s findings neglect cost factors like capital requirements, risk margins, and profit margins, which customers would have to pay via their premium. These additional costs reduce the energetic retrofitting investment’s net present value beyond the fair premium and, thus, might limit the investment’s attractiveness. Ideally, national governments (partially) reimburse the costs of energy efficiency insurances in the form of public subsidies to promote the heat transition by providing risk mitigation tools. To make this practicable, future research should calculate and analyze the energy efficiency insurances’ market premiums based on RP1’s pricing approach.
- The developed forecast model does not consider socioeconomic and behavioral factors, although the literature has scientifically documented their influence on energy consumption very well (Rehdanz 2007). Future research should investigate how contract conditions must be adjusted depending on different energetic retrofitting levels (e.g., at least triple glazing, 15 cm outer wall insulation), to improve the insurance portfolios’ risk and return from the perspective of an insurer.

- Finally, RP1 only considers natural gas and heating oil as economic risk factors. However, heat pumps (electricity) and biomass boilers have to take up significant shares in order to promote the heat transition in Germany (Fraunhofer IWES/IBP 2017). Future research should develop energy efficiency insurances specifically for renewable energy sources and analyze their contribution to the heat transition.

The limitations of RP2 that provide opportunities for future research are:

- Since RP2 almost completely adopts RP1's fair premium pricing approach, RP2's analysis of diversification effects can be repeated for each relaxation of RP1’s limitations, which are inherited.
- Future research should enhance RP2's exemplarily selected insurance portfolio and conduct a structured analysis of diversification effect that takes into account various existing types of insurance portfolios, for example, add crop insurance products (Annan and Schlenker 2015) and consider multiple countries with different climate conditions. Countries in which not only space heating, but also space cooling is a main energy demand factor, are especially promising.
- Finally, future research should analyze to which extent the observed portfolio diversification effects would actually suit the Solvency II context. Currently, academics have only proven the reduction of standard deviation and Value at Risk for exemplary insurance products, but they have not yet considered detailed legal requirements.

RP3 highlights several research questions that interdisciplinary researchers and practitioners, who strive to further develop and implement energy forecast models, could find interesting:

- The quantile regression model that the author presents in RP3 does not include occupancy parameters, which potentially increase prediction accuracy and enable enhanced analysis (Rehdanz 2007). The number of residents and their employment status would be particularly interesting input variables. Furthermore, the building component characteristic classification could be improved, which was not possible, owing to the given data set (e.g., thermal window properties based on product key figures, such as the u-value instead of the used five window classes: single, double old, double modern, triple, and heat-insulated).
- As is often the case with data-based approaches, the data set’s quality could be further improved to sharpen the analysis. In the future, researchers should specifically focus on

the households, which provided the data without any verification mechanisms. Future research should, therefore, use secondary data sources like the official land registry, orthophotos, as well as light detection and ranging (LiDAR) data to model individual building envelopes (Kabolizade et al. 2010). This increases the number of attributes that researchers can consider and enables data validity verification.

- RP3 emphasizes the advantages of quantile regression approaches in the heating forecast model context, as building attributes influence the heating energy consumptions' quantiles differently. Further research could compare different quantile regression models for the residential heating energy sector, such as vine copula-based quantile regression (Kraus and Czado 2017), quantile regression forests (Nguyen et al. 2015), and Support Vector Machine quantile estimation (Hwang and Shim 2005) to improve prediction accuracy.
- The author limited the paper to the most common D-vine copula specifications (vine structure selection, copula family, and continuous convolution), but is well aware of the abundance of possible specifications and parameterizations. Future research should also consider C-vine and R-vine structures and should improve the variable selection by applying standard methods, such as the forward selection approach (Blanchet et al. 2008).

Taken together, these potential research opportunities provide various starting points for future research on risk and return management for the heat transition.

V.2.2 Future research identified in Section III: Risk and return management for business models at the interface of the energy, heat, and transport transition

The limitations of RP4 that provide opportunities for future research are:

- The parts of a decision support system, which the author presents in RP4, is designed for landlord-to-tenant electricity supply models without energy storage capacities and neglects electric vehicles' load profiles. However, these two technological trends can improve the returns on the landlord-to-tenant electricity supply investments and should thus be considered in future research. Owing to decreasing energy storage costs, these two trends will be more relevant in the future and should lever the landlord-to-tenant electricity supply model's business opportunities. For example, landlords can provide charging infrastructure in addition to apartment rental.

- RP4 assumes that the tenants’ load profile stays the same during the whole investment period and ignores changing occupant behavior. For example, the probability that a young couple will fall pregnant can be relatively high; a pregnancy can therefore potentially change their lifestyle and, consequently, their energy load profiles significantly (Fischer et al. 2015). Therefore, future research should relax this assumption with an additional model for extrapolating household characteristics over time to improve the prediction accuracy (Peichel et al. 2012).
- How the tenants' acceptance and, thus, willingness to participate in landlord-to-tenant electricity supply models will develop over time, is also not clear, since, for example, high termination rates (e.g., through tenant changeover) can have a harsh impact on profitability. Long-term studies of landlord-to-tenant electricity supply models can offer the necessary transparency and should define best practices for customer (tenants) relationship management. Future research can model this aspect as an additional risk factor.
- Finally, RP4 does not yet model the landlord-to-tenant electricity supply models' energy price risks and operating cost development. Future research should consider the drivers of electricity price dynamics (Mosquera-López and Nursimulu 2019) and apply adequate stochastic approaches, such as ARIMA, GARCH, or stochastic volatility models (Chan and Grant 2016; Kumar et al. 2018)

All in all, these potential research opportunities provide various starting points for future research aimed at designing and developing new business models at the interface of the energy, heat, and transport transition

V.2.1 Future Research identified in Section IV: IT risk management as prerequisite for low-carbon transitions

The limitations of RP5 that provide opportunities for future research are:

- Although RP5 focuses on IT project risks, future research should adapt the presented method and extend its scope with the Internet of Things (IoT) solution’s risks (e.g., risks of intelligent and connected heating systems). Thibaud et al. (2018), for example, highlight the importance of IoT-related risks specifically in the energy, transport, and infrastructure sector, which a standardized risk assessment framework can address.

- To scrutinize the generality of RP5’s risk management method, future research could perform similar case studies in other companies across multiple sectors. Observing how the method performs with agile project management methods is particularly interesting as the case study company under consideration applied a strict waterfall method. Whether the method has value for other companies that do not base decisions on integrated risk and return aspects, is also not clear.
- Following Häckel and Hänsch (2014), IT portfolio management on a synchronized level has great economic potential by balancing the risk and return of a company’s IT landscape. Currently, the presented method neglects the IT projects' interdependencies and, thus, does not yet support automatic risk aggregation. Researchers should consider these interdependencies, especially when selecting risk mitigation measures on an enterprise level. Future research should adopt this method, as well as the standardized output, to identify and argue for reasonable mitigation measure portfolios to reduce a company’s IT risk landscape.
- Different companies frequently carry out relatively similar IT projects, such as introducing standardized cloud services, and thus encounter similar risks and challenges (Krutz and Vines 2010). Future research could compare different risk assessments with the corresponding selected mitigation measures of similar projects to identify best practices and frequent shortcomings. With a large number of evaluated projects and solutions, self-learning systems could emerge that incorporate their users' initial recommendations and actively support them.

Since IT risk management is a challenging issue not only for low carbon transitions, these potential research opportunities provide various starting points for future research.

V.3 Conclusion

Summarizing the research papers presented in Chapter II, III and IV, this doctoral thesis contributes to the risk and return management fields for the heat, energy, and transport transition. The presented research papers specifically investigate fundamental aspects that contribute to the dissemination of energy efficiency insurance products and the landlord-to-tenant electricity supply model, which are promising business models for reducing CO_2 emissions. As integrated risk and return management will play an important role in the low-carbon transition field in times of digitalization, this doctoral thesis provides first supportive approaches.

V.4 References

Akerlof, George A. (1970): The Market for "Lemons". Quality Uncertainty and the Market Mechanism. In *The Quarterly Journal of Economics* 84 (3), pp. 488–500.

Annan, Francis; Schlenker, Wolfram (2015): Federal Crop Insurance and the Disincentive to Adapt to Extreme Heat. In *American Economic Review* 105 (5), pp. 262–266.

Blanchet, F. Guillaume; Legendre, Pierre; Borcard, Daniel (2008): Forwad selection of explanatory variables. In *Ecology* 89 (9), pp. 2623–2632.

Chan, Joshua C.C.; Grant, Angelia L. (2016): Modeling energy price dynamics. GARCH versus stochastic volatility. In *Energy Economics* 54, pp. 182–189.

Chapman, Lee; Azevedo, Juliana Antunes; Prieto-Lopez, Tatiana (2013): Urban heat & critical infrastructure networks: A viewpoint. In *Urban Climate* 3, pp. 7–12.

Denner, Marie-Sophie; Püschel, Louis Christian; Röglinger, Maximilian (2018): How to Exploit the Digitalization Potential of Business Processes. In *Bus Inf Syst Eng* 60 (4), pp. 331–349.

Fischer, David; Härtl, Andreas; Wille-Haussmann, Bernhard (2015): Model for electric load profiles with high time resolution for German households. In *Energy and Buildings* 92, pp. 170–179.

Fraunhofer IWES/IBP (2017): Wärmewende 2030. Schlüsseltechnologien zur Erreichung der mittel- und langfristigen Klimaschutzziele im Gebäudesektor. Studie im Auftrag von Agora Energiewende. Edited by Agora Energiewende. Available online at https://www.agora-energiewende.de/fileadmin2/Projekte/2016/Sektoruebergreifende_EW/Waermewende-2030_WEB.pdf, checked on 4/1/2019.

Gatzert, Nadine; Wesker, Hannah (2012): A Comparative Assessment of Basel II/III and Solvency II. In *Geneva Pap Risk Insur Issues Pract* 37 (3), pp. 539–570.

Greening, Lorna; Greene, David L.; Difiglio, Carmen (2000): Energy efficiency and consumption — the rebound effect — a survey. In *Energy Policy* 28 (6-7), pp. 389–401.

Häckel, Björn; Hänsch, Florian (2014): Managing an IT portfolio on a synchronised level, or: The costs of partly synchronised investment valuation. In *Journal of Decision Systems* 23 (4), pp. 388–412.

Hwang, Changha; Shim, Jooyong (2005): A Simple Quantile Regression via Support Vector Machine. In David Hutchison, Takeo Kanade, Josef Kittler, Jon M. Kleinberg, Friedemann Mattern, John C. Mitchell et al. (Eds.): Advances in Natural Computation, vol. 3610. Berlin, Heidelberg: Springer Berlin Heidelberg (Lecture Notes in Computer Science), pp. 512–520

Kabolizade, Mostafa; Ebadi, Hamid; Ahmadi, Salman (2010): An improved snake model for automatic extraction of buildings from urban aerial images and LiDAR data. In *Computers, Environment and Urban Systems* 34 (5), pp. 435–441.

Kraus, Daniel; Czado, Claudia (2017): D-vine copula based quantile regression. In *Computational Statistics & Data Analysis* 110, pp. 1–18.

Krutz, Ronald L.; Vines, Russell Dean (2010): Cloud security. A comprehensive guide to secure cloud computing. Indianapolis, Ind.: Wiley. Available online at http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10419391.

Kumar, Vipin; Singh, Nitin; Singh, Deepak Kumar; Mohanty, S. R. (2018): Short-Term Electricity Price Forecasting Using Hybrid SARIMA and GJR-GARCH Model. In Gregorio Martinez Perez, Krishn K. Mishra, Shailesh Tiwari, Munesh C. Trivedi (Eds.): Networking Communication and Data Knowledge Engineering, vol. 3. Singapore: Springer Singapore (Lecture Notes on Data Engineering and Communications Technologies), pp. 299–310.

Mills, Evan (2003): Risk transfer via energy-savings insurance. In *Energy Policy* 31 (3), pp. 273–281.

Mosquera-López, Stephanía; Nursimulu, Anjali (2019): Drivers of electricity price dynamics: Comparative analysis of spot and futures markets. In *Energy Policy* 126, pp. 76–87.

Nguyen, Thanh-Tung; Huang, Joshua Z.; Nguyen, Thuy Thi (2015): Two-level quantile regression forests for bias correction in range prediction. In *Mach Learn* 101 (1-3), pp. 325–343.

Peichel, Andreas; Pestel, Nico; Schneider, Hilmar (2012): Does size matter? The impact of changes in household structure on income distribution in Germany. In *Review of Income and Wealth* 58 (1), pp. 118–141.

Rehdanz, K., (2007): Determinants of residential space heating expenditures in Germany. In *Energy Economics* 29 (2), pp. 167–182.

Rothschild, Michael; Stiglitz, Joseph (1976): Equilibrium in Competitive Insurance Markets. An Essay on the Economics of Imperfect Information. In *The Quarterly Journal of Economics* 90 (4), pp. 629–649.

Thibaud, Montbel; Chi, Huihui; Zhou, Wei; Piramuthu, Selwyn (2018): Internet of Things (IoT) in high-risk Environment, Health and Safety (EHS) industries: A comprehensive review. In *Decision Support Systems* 108, pp. 79–95.