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EBS Universität für Wirtschaft und Recht
EBS Business School

Inaugural Dissertation

In order to obtain the Academic Degree of
Doctor Rerum Politicarum (Dr. rer. pol.)

Three Essays on Sustainable Supply Chain Management – Towards Sustainable Supplier Selection and Sustainable Sourcing

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Submission Date: 31 July 2017

To my Family

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List of Abbreviations

Abbreviation	Full name
AD	Axiomatic design
AHP	Analytic hierarchy process
AI	Artificial intelligence
BMW	Bayerische Motoren Werke AG
CI	Consistency index
CO_2	Carbon dioxide
CoC	Code of conduct
CR	1) Corporate responsibility department
	2) Consistency ratio
CSR	Corporate social responsibility department
DAX	Deutscher Aktienindex (German blue chip stock market index)
DEMATEL	Decision-making trial and evaluation laboratory
EBIT	Earnings before interest and taxes
GHG	Greenhouse gas protocol
HR	Human resources department
ICT	Information and communication technology
KPI	Key performance indicator
MCDM	Multiple criteria decision-making
MP	Mathematical programming
NGO	Non-governmental organization
OM	Operations management department
R&D	Research and development department
RI	Random consistency index
SISP	Scaled inverse sustainability performance
SP	Sustainability performance
SCM	Supply chain management
SSCM	Sustainable supply chain management
TBL	Triple-bottom line
TCO	Total cost of ownership
TOPSIS	Technique for order preference by similarity to ideal solution
TSO	Total sustainability of ownership
UN	United Nations
USP	Unique selling point
VW	Volkswagen AG
WSISP	Weighted scaled inverse sustainability performance

I. Introduction

Within the past fifty years, the world has been changing substantially: Fundamental progress in diverse areas such as technology, medicine, mobility, energy supply, communication, and IT has been made (United Nations, 2015). Nowadays, we are living in a globalized world with a higher level of prosperity, increased life expectancy, and have been more connected through digitalization and advances in mobility than ever before (United Nations Development Programme, 2016). With this change, however, also new issues have arisen: Our planet has to nourish more than seven billion people, social inequalities are growing worldwide, and ecological concerns such as climate change are discussed in politics and business.

The concept of sustainability refers to these issues and embraces the triad of profit, people, and planet which is known as the triple-bottom line (Elkington, 1998; Kleindorfer et al., 2005). To achieve the targets of sustainability, which are often described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" based on the Brundtland report in 1987, all members of the global community such as politicians, customers, and companies have to be involved. In line with that notion, also multinational companies and their suppliers are required to respect the topic of sustainability. In literature, this has been studied under the term of sustainable supply chain management (SSCM) which is defined as the consideration of economic, environmental, and social issues to improve the performance of the supply chain as a whole in the long-term (Carter and Rogers, 2008).

This thesis explores in three interlinked essays the question of how companies realize sustainability in their companies and along their supply chains and how this process can be supported by means of models and tools. Thereby, the thesis focuses on companies' sustainability activities, sustainable supplier selection, and sustainable order allocation decisions.

Implementing SSCM has been proven to increase a company's and its suppliers' financial performance and competitive advantage (Ağan et al., 2016; Campbell, 2007; Hollos et al., 2012; Reuter et. al., 2012). Thereby, the procurement department plays a vital role for driving sustainability realization: As strategically relevant entrance gate to the firm, the procurement function significantly determines a firm's level of sustainability by selecting sustainable suppliers and products (Krause et al., 2001; Miemczyk et al., 2012). However, managing global supply chains has become more complex through the integration of sustainability (Hoejmose and Adrien-Kirby, 2012; Seuring and Müller, 2008; Zhang et al., 2015). SSCM researchers acknowledge this complexity and investigate the topic of SSCM with the help of different theoretical approaches and theories to understand the complex context and to develop descriptive models and supportive tools (Ashby et al., 2012; Brandenburg et al., 2014; Johnsen et al., 2017; Sarkis et al., 2011; Taticchi et al., 2015). Yet, most of the studies either focus on environmental or on social aspects instead of investigating all three aspects of sustainability, i.e. environmental, social, and economic aspects (Lueg and Radlach, 2016; Zhang et al., 2015). Moreover, there is a need to develop comprehensive SSCM models and frameworks, on the one hand, and practical tools to facilitate the implementation of SSCM, on the other hand (Ashby et al., 2012; Orji and Wei, 2014; Taticchi, 2015). The first essay of

this thesis develops a theoretical model to encompass the process of sustainability implementation. Based on the institutional theory, the following research questions are addressed:

> *(1) How do companies respond to institutional pressures on sustainability; (2) Which moderators influence the effect of institutional sustainability pressures; (3) Which different levels of sustainability pervasion across companies can be identified?*

The essay "Institutional pressures and responses in the field of sustainability: The moderating effects of expected sustainability benefits and top management support" answers these research questions and proposes a model to depict the impact of institutional pressures on sustainability, determines sustainability implementation activities, and identifies moderators of institutional pressures to explain different levels of sustainability implementation in this essay defined as sustainability pervasion. Institutional theory states that institutional pressures, i.e. coercive, mimetic, and normative pressures, induce isomorphic organizational structures and processes (DiMaggio and Powell, 1983). Although institutional theory has been used in the context of SSCM, our knowledge of how companies respond to institutional pressures is still in its infancy (Glover et al., 2014).

In the first essay, institutional theory is applied to the topic of sustainability and embedded in a qualitative research framework according to Strauss and Corbin (1990). In a multiple case study of eight multinational companies in the manufacturing and service providing sectors, the question of how institutional pressures affect companies' sustainability activities is empirically investigated. The findings – based on 35 interviews and triangulated with supplementary information – first provide evidence that institutional pressures evoke isomorphic sustainability responses resulting in average-sustainability pervasion levels.

Second, this essay suggests that the moderators "expected sustainability benefits" and "top management support" impact institutional pressures on sustainability in such a way that heterogeneous – the term anisomorphic as contrast to isomorphic is introduced – sustainability responses are established within companies and along their supply chain resulting in supra- respectively sub-sustainability pervasion levels. The outcomes are presented in an extended research model and testable propositions are proposed. The details of the results of the first essay are provided from page 24 onwards.

The first essay approaches the topic of SSCM by studying companies' actual sustainability activities and construction of a theoretical model. The other two essays specifically develop practical models and mathematical tools for sustainable sourcing, more precisely for sustainable supplier selection and order allocation decision.

In recent decades, value creation has shifted, to a large extent, from the original equipment manufacturer (OEM) towards its suppliers (Schiele, 2007; Van der Rhee et al., 2009). Accordingly, the selection of sustainable suppliers is crucial as it reduces operational and reputational risks, essentially determines a manufacturer's sustainability performance, and thus contributes to the overall corporate performances (Campbell, 2007; Cegarra-Navarro et al., 2016; Dubey et al., 2016; Schaltegger, 2011). However, sustainable supplier selection is a complex decision with inherent problems in business practice: Multiple decision makers with opposing objectives have to select sustainable suppliers by evaluating multiple sustainable selection criteria and measuring suppliers' sustainability performances in multiple units. Therefore, the second paper of this thesis reflects the following research questions:

(1) How can multiple decision makers' opposing perspectives be aligned and integrated into a decision model; (2) How can trade-offs between multiple sustainability criteria be balanced; (3) How can suppliers' sustainability performances be effectively measured and compared?

The paper "Towards integrated sustainable supplier selection with the total sustainability of ownership method" elaborates on these research questions and introduces a practical model for sustainable supplier selection. By linking the concepts of analytic hierarchy process (AHP) (Kubicz et al., 2015; Saaty, 1990) and total cost of ownership (TCO) (Degraeve et al., 2000; Ellram 1993; Ellram and Siferd, 1998), we have developed the total sustainability of ownership (TSO) method. The TSO method integrates both subjective perspectives of the involved decision makers and objective sustainability performance measurements of the suppliers to be selected. Testing our TSO method in a scenario-based experimental pre-test and a multiple case study with three multinational high-tech firms and 33 participants in total, the contribution of this paper is twofold: First, it offers detailed insights into how decision makers from different departments evaluate sustainable sourcing criteria. Second, it presents both a conceptual and mathematical model for selecting the most sustainable supplier by considering multiple decision makers' criteria evaluations and suppliers' sustainability performances. In addition, we enhance the AHP method by proposing a new evaluation scale and establishing transitive relations which reduce the method's complexity and enhance its consistency. The detailed results and the conclusion are presented from page 72 onwards.

Previous literature reviews have determined that SSCM has mostly been studied by focusing on conceptual models which results in a lack of quantitative sustainable sourcing models

(Ashby et al., 2012; Hassini et al., 2012; Miemczyk et al., 2012; Seuring, 2013; Tang and Zhou, 2012; Taticchi et al., 2015). In order to contribute to a more profound understanding of sustainable sourcing by means of a quantitative model, the third essay of this thesis develops a mathematical model for sustainable supplier selection and order allocation decisions. It focuses on the following research questions:

> *(1) How can the newsvendor model be adopted to sustainable sourcing considering all three sustainability dimensions holistically; (2) How can optimal order allocations be determined in dependence on suppliers' sustainability levels; (3) How can suppliers' sustainability levels influence price and demand of the manufacturer's end product?*

The essay "A quantitative sustainable sourcing model for supplier selection and order allocation" considers these research questions. Based on the newsvendor model, we develop a linear programming model to select suppliers and determine optimal order quantities constricted by uncertain demand and salvage value (Dada et al., 2007; Zhang and Zhang, 2011). In our mathematical formulation, the suppliers' sustainability levels are reflected by three factors: They determine the salvage value as well as demand and price of the end product. Having empirically tested our mathematical model by 42 scenarios and sensitivity analyses, the findings of the essay are threefold: First, the model has outlined, that the benefit of higher order capacities from a less sustainable supplier pool does not consistently outweigh the reduction in end product price achievable by a less sustainable end product. Second, the benefits of higher stocks does not always compensate the additional fixed charges when procured from other suppliers in the same pool. Third, sustainability-sensitive demand and its coefficient of variation have to be reflected in sustainable supplier selections and order

allocation decisions to optimize profits. A comprehensive presentation of testing the model and discussion of the results is given from page 94 onwards.

In summary, the three essays of this thesis study the subject of sustainable supply chain management from different perspectives and with different methodical approaches. Thereby, they both contribute to academic research and offer practical support. Moreover, avenues for future research are outlined in each essay. Figure I-1 gives an overview of the three essays with respective research motivation, theoretical approach, research method, and, finally, the academic and practical contributions.

Three Essays on Sustainable Supply Chain Management

	Paper I **Institutional Pressures and Responses in the Field of Sustainability: The Moderating Effects of Expected Sustainability Benefits and Top Management Support**	**Paper II** **Towards Integrated Sustainable Supplier Selection with the Total Sustainability of Ownership Method**	**Paper III** **A Quantitative Sustainable Sourcing Model for Supplier Selection and Order Allocation**
Motivation	• Explore companies' isomorphic & heterogeneous sustainability responses to institut. pressures • Identify moderators of institutional pressures on sustainability & explain different levels of companies' sustainability pervasion • Develop a theoretical model of institutional pressures on sustainability	• Investigate the three complications of sustainable supplier selection, i.e. multiple departments, multiple sustainability selection criteria, multiple measurements of suppliers' sustainability performances • Develop a practical model for sustainable supplier selection	• Determine optimal order quantities under consideration of capacity & price constraints • Integrate sustainability levels that determine end product's price & expected demand • Develop a mathematical model for sustainable supplier selection
Theoretical Approach	• Institutional theory (Bhakoo and Choi, 2013; DiMaggio and Powell, 1983; Glover et al., 2014; Sarkis et al., 2011; Zhu and Sarkis, 2007) • Sustainability literature (Baumgartner and Ebner, 2010; Carter and Rogers, 2008; Elkington, 1998; Kleindorfer et al., 2005)	• Sustainable supplier selection literature (Brandenburg et al., 2014; Foerstl et al., 2013; Tang and Zhou, 2012; Ashby et al., 2012) • Quantitative supplier selection model literature (Brandenburg et al., 2014; Seuring, 2013; Tang and Zhou, 2012)	• Newsvendor theory (Pan, 1989; Awasthi et al., 2009; Zhang and Thang, 2011) • Quantitative sustainable sourcing model literature (Miemczyk et al., 2012; Nouira et al., 2014; Raz et al., 2013;Tang and Zhou, 2012)
Research Method	• Development of a qualitative research model • Multiple case study with eight companies in the manufacturing & service providing sector • Analysis of 35 interviews to derive a research model with propositions (grounded theory)	• Development of a qualitative and quantitative case study model & application to practice • Scenario-based experimental pre-test • Multiple case study with three companies in the high-tech sector, 33 participants in total	• Development of a mathematical model formula • Consideration of capacity constraints, component prices & fixed charges • Empirically testing the model by 42 scenarios & sensitivity analyses
Contribution	• Elaboration on companies' responses to institutional pressures by presenting their sustainability activities in detail • Identification of moderators "expected sustainability benefits" & "top management support" impacting institutional pressures on sustainability • Introduction of the concept of anisomorphism as counterpart to isomorphism & determination of three levels of sustainability pervasion (supra, average, sub)	• Development of a conceptual model depicting sustainable supplier selection • Derivation of a comprehensive mathematical model for sustainable supplier selection by an integrated AHP-TSO method • Suggestion of measures for suppliers' sustainability performances • Proposal of a new AHP evaluation scale • Enhancement of the AHP method by introduction of transitive relations to reduce complexity & raise consistency	• Examination of a sustainable sourcing problem with supplier selection & order allocation • Attention to interdependencies of suppliers' sustainability and end product's price & demand • Development of a mathematical sourcing model with suppliers' sustainability levels as determining factor for end product's price & demand • Establishment of a target function to maximize a manufacturer's profit under the constraints of sustainability & capacity

Figure I-1: Overview of the three essays of this thesis.

II. Institutional Pressures and Responses in the Field of Sustainability: The Moderating Effects of Expected Sustainability Benefits and Top Management Support

Abstract

The need for implementing sustainability in companies and along their supply chains has become a major concern for Sustainable Supply Chain Management (SSCM). Although SSCM has been studied in multiple studies, the knowledge about how institutional pressures – coercive, mimetic, and normative pressures – impact companies' sustainability activities is still at an early stage.
In this paper, a model is developed for conceptualization the impact of institutional pressures on sustainability, sustainability activities in response to institutional pressures are explored, and the outcome defined as sustainability pervasion is studied. Based on the findings from a multiple case study of eight multinational companies in the manufacturing and service providing sectors, first evidence is supported that institutional pressures induce isomorphic sustainability activities and result in average-sustainability pervasion levels. Second, it is proposed that institutional pressures on sustainability are impacted by the moderators "expected sustainability benefits" and "top management support" which induce anisomorphic sustainability activities and result in supra- respectively sub-sustainability pervasion levels. Finally, the findings are presented in an extended research model and testable propositions are derived.

Keywords: *Institutional pressures and moderators; sustainability activities; isomorphism and heterogeneity; sustainability pervasion; multiple case study.*

1. Introduction – Need for a comprehensive model of companies' sustainability responses to institutional pressures

A historic breakthrough has taken place: At the climate summit of the United Nations in Paris in 2015, 195 countries agreed on a binding contract to limit global warming to two degrees Celsius. To reach this target, all members of the global community have to make sustainable efforts. Thus, companies are also required to strengthen their sustainability activities. There are many companies that have already committed themselves and their suppliers to sustainability, i.e. the pursuit of the triple-bottom line embracing economic, social, and environmental issues (Carter and Rogers, 2008; Kleindorfer et al., 2005). For instance, firms have introduced codes of conduct to ensure certain rules of green and social behavior in business practice along the supply chain. Bayer AG, Bayerische Motoren Werke AG (BMW), Siemens AG and SAP AG, for example, have been awarded for their sustainability activities and ranked in the Dow Jones Sustainability Index (DJSI) for 15 consecutive years (DJSI, 2014).

However, there are firms which have been convicted for non-sustainable behavior. For instance, Volkswagen AG (VW), one of the largest automotive companies in the world, faces a scandal after manipulating emissions values. Consequently, VW was removed from the DJSI (DJSI, 2015). For the same reason, Fiat Chrysler Automobiles N.V. will also no longer be listed in the DJSI (DJSI, 2017). Hence, there are obviously discrepancies between firms which are actively engaged in sustainability efforts and others which lag behind regarding their sustainability commitment.

In academic research, implementing sustainability within companies and along their supply chains has been studied with the help of theories, such as stakeholder theory,

resource-based view and institutional theory (Johnsen et al., 2017; Touboulic and Walker, 2015). In this paper, the phenomenon of different levels of sustainability pervasion is studied – which is introduced as degree of sustainability implementation – with the help of institutional theory.

Institutional theory indicates that organizations become similar over time (isomorphic) with regards to their organizational structures and processes (DiMaggio and Powell, 1983). This phenomenon of isomorphism is evoked by institutional pressures that are subdivided into coercive, mimetic, and normative pressure. Coercive pressure is exerted by laws and regulations, mimetic pressure is based on uncertainty inducing companies to copy their competitors, and normative pressure is caused by professionalization through similar educational background and professional networks (DiMaggio and Powell, 1983).

The application of institutional theory to sustainable supply chain management is, however, still in its infancy (Glover et al., 2014). The threefold perspectives of sustainability are often not considered simultaneously, but institutional theory is used to explain either social or environmental activities of the firms (Campbell, 2007; Tate et al., 2011). Moreover, the fact of heterogeneous levels of sustainability pervasion instead of isomorphic levels should be investigated by introducing moderators of institutional pressures (Bhakoo and Choi, 2013; Sarkis et al., 2011; Zhu and Sarkis, 2007).

Thus, this essay explores the impact of institutional pressures on companies' sustainability behavior and investigates how moderators influence the degree of sustainability implementation within companies and along their supply chains by means of a multiple case study.

The remainder of this paper is divided into four sections: First, a review of the literature on sustainability and institutional theory will be provided. In addition, a research framework applying institutional theory in the context of sustainability will be developed. Second, a qualitative multiple case study will be presented in the notion of grounded theory. Third, the data analysis will be presented including the derivation of the propositions and the development of an extended research model. In the final section, the main findings will be summarized and both managerial implications and avenues for future research will be outlined.

2. Literature Review – Developing the research framework based on sustainability and institutional theory

The theoretical framework of this study is based on two literature streams: First, it is based on the research on sustainability and, second, on the theory of institutional pressures. Both literature streams will be presented to provide a review on each topic, identify the current research gaps and derive the extended research framework.

2.1. Sustainability Literature

Sustainability with its threefold concept embracing environmental, social, and economic aspects known under the notion of the triple-bottom line (TBL) (Baumgartner and Ebner, 2010; Elkington, 1998; Kleindorfer et al., 2005; Kleine and Hauff, 2009) has become a major topic in scientific research and global business. Companies focus on ecological and social sustainability along their value chains to achieve economic success in the long term (Campbell, 2007; Porter and Van der Linde, 1995). By getting involved with sustainability companies aim at both avoiding damage to their reputations (Campbell, 2007) and creating competitive advantages (Foerstl et al., 2010). Therefore, globally

operating corporations increasingly introduce sustainable supply chain management (SSCM) by considering in their sourcing decisions issues such as emissions, waste, hazardous materials, child labor, working conditions and compliance (Ferrin and Plank, 2002; Miemczyk et al., 2012; Walker and Jones, 2012; Zhu and Sarkis, 2007).

A multitude of sustainability research studies have been conducted to understand fundamental processes as well as to identify implementation drivers and barriers within organizations and along supply chains (Giunipero et al., 2012; Seuring and Müller 2008; Walker and Jones, 2012). In these studies, diverse theories, such as transaction cost economics, stakeholder theory, and institutional theory, have been used to explain institutions' sustainability behavior (Carter and Easton, 2011; Helms et al. 2012; Johnsen et al., 2017; Touboulic and Walker, 2015). Institutional theory is a relevant framework to explain organizational behavior (DiMaggio and Powell 1983). This will be presented in the next section.

2.2. Institutional Theory

Institutional theory indicates that "structuration of organizational fields" (Giddens, 1979) as well as "uncertainty and constraint" (DiMaggio and Powell, 1983) lead to "homogeneity in structure, culture, and output" (ibid.). This process of homogenization is defined as isomorphism by Hawley (1968), "a constraining process that forces one unit in a population to resemble other units that face the same set of environmental conditions". Institutional isomorphic change is caused by three pressures: First, there is coercive pressure based on legitimacy issues and political factors: Formal pressures by laws or regulations as well as informal pressures by non-governmental organizations (NGOs) drive homogenization processes of organizations (DiMaggio and Powell, 1983).

Second, there is mimetic pressure stemming from uncertainty of the future: Companies imitate activities of others in their sector to achieve legitimacy (ibid.). Third, there is normative pressure as a result of increasing professionalization: Managers have similar educational backgrounds as they visit the same universities and complete the same training and hence spread the same taught knowledge and management practices in their companies (ibid.).

Interestingly, institutional homogenization processes will take place with or without evidence for an increase of internal organizational efficiency (DiMaggio and Powell 1983; Meyer and Rowan, 1977). Nevertheless, there are some advantages of similarity between organizations, such as easier transactions with each other, compliance with standardized public or private requirements, and attraction of high-potential employees through achievement of legitimacy and better reputation (Bhakoo and Choi, 2013). The following paradox occurs: With the objective of change, organizations are becoming more and more homogeneous. Change leads to isomorphism.

2.3. Institutional Theory applied to Sustainability

In the previous sections, the concepts of sustainability and institutional theory were presented. In the following, the application of institutional theory to the subject of sustainability will be reviewed.

Hitherto, several studies have used institutional theory to explain companies' sustainable behavior in different contexts (e.g. Zhu and Sarkis, 2007; Glover et al., 2014; Sarkis et al., 2011; Tate et al., 2011; Wu et al., 2012). For instance, Glover et al. (2014) studied the impact of institutional pressures on suppliers to adopt environmental practices in the dairy sector. Like that paper, however, most of the research to date has focused either on

environmental or social sustainability and its link to institutional theory. An overview of the research on sustainability applying institutional theory is given in Table II-1.

Table II-1: Illustrative literature review regarding empirical research on sustainability within an institutional theoretical framework.

Authors	Methodology	Sustainability Dimension	Institutional Theory
Bhakoo and Choi, 2013	Empirical research (case study)	Social	Institutional theory applied on the healthcare supply chain
Boselie et al., 2003	Empirical research (survey)	Social	Combination of institutional theory with human resource management theory
Campbell, 2007	Theoretical research (conceptual)	Social	Institutional theory on corporate social responsibility
Delmas and Toffel, 2008	Empirical research (survey)	Environmental	Combination of old and new institutionalism to explore organizational strategies
DiMaggio and Powell, 1983	Theoretical research (conceptual)	n.a.	Development of the concept of institutional isomorphism
Glover et al., 2014	Empirical research (case study)	Environmental	Institutional theory to explore energy consumption in dairy supply chains
Helms et al., 2012	Empirical research (survey)	Social	New institutional practices of social responsibility standards
Oliver, 1991	Theoretical research (conceptual)	n.a.	Link of institutional with resource-based theory to predict strategic responses to institutional pressures
Sarkis et al., 2011	Theoretical research (literature review)	Environmental	Review of institutional theory and green supply chain management
Schaefer, 2007	Empirical research (case study)	Environmental	Linkage of institutional theory and environmental management systems
Tate et al., 2011	Theoretical research (conceptual)	Environmental	Institutional pressures on adoption of environmental practices
Wu et al., 2012	Empirical research (survey)	Environmental	Application of institutional theory to green SCM in Taiwan's apparel industry
Zhu and Sarkis, 2007	Empirical research (survey)	Environmental	Institutional pressure as moderators of green SCM practices and organizational performance

Institutional theory describes isomorphic behavior. However, companies reveal heterogeneous levels of sustainability pervasion. According to Bhakoo and Choi (2013), heterogeneity is the result of different responses to institutional pressures. Moreover, there are calls for further investigations of moderators influencing the impact of the

isomorphic pressures (Glover et al., 2014; Helms et al., 2012; Sarkis et al., 2011; Wu et al., 2012). For instance, Helms et al. (2012) state that most research has tried to explain the conformity in prevailing sustainability practices rather than exploring the divergences. Accordingly, there is a need to elaborate on how the three types of institutional pressure affect companies' sustainability commitment and under what conditions isomorphic or anisomorphic responses occur. This essay integrates all three TBL aspects to embrace the concept of sustainability holistically and investigates it with the help of institutional theory. Moreover, the request of Delmas and Toffel (2008) for advanced research on "how and why organizations respond differently to institutional pressures" (ibid.) is considered. In addition, this paper identifies potential moderators which impact institutional isomorphic pressures as Oliver (1991) demands. In their literature review on SCM and sustainability, Ashby et al. (2012) identify a need for more "tangible outputs such as an explicit research framework". Thus, this essay considers the depicted requests and develops an explicit model to depict the process of sustainability pervasion embedded in institutional theory and investigates its influencing moderators.

2.4. Research Questions and Research Framework

Two research gaps could be identified from the reviewed literature regarding the application of institutional theory to the field of sustainability: (1) Previous studies focus either on social or environmental sustainability dimensions instead of considering a holistic approach based on the TBL concept; (2) Existing models of institutional theory in the context of sustainability need to be expanded by identifying moderators of institutional pressure and examining heterogeneous levels of sustainability pervasion in contrast to the anticipated isomorphic behavior.

Hence, this essay addresses the following research questions:

1. How do companies respond to institutional pressures on sustainability, i.e. by which sustainability activities?
2. Which moderators influence the effect of institutional sustainability pressures?
3. What different levels of sustainability pervasion across companies can be identified?

In this study, it is empirically explored how institutional pressures impact companies' sustainability activities, what moderators may interact and how the outcome towards sustainability pervasion can be defined. Therefore, the model of tripartite institutional pressures (DiMaggio and Powell, 1998) is applied in the context of sustainability and linked with the qualitative research framework of Strauss and Corbin (1967). Strauss and Corbin (1990) established a research framework for qualitative studies which depicts a causal chain of five stages known as grounded theory (Figure II-1).

Based on the depicted theories, an extended research framework is developed as shown below (Figure II-2): Social and environmental grievances are inherent causal conditions that evoke the phenomenon of sustainability, the pursuit of improving the world in the long term. This sustainability target is embedded in the context of institutional pressure which is normative, coercive, and mimetic pressure. These pressures, impacted by moderators yet to be identified, lead to organizations' sustainability responses, i.e. their sustainability activities. As a result, there are both homogeneous (isomorphic) levels of sustainability pervasion as well as heterogeneous (anisomorphic) levels.

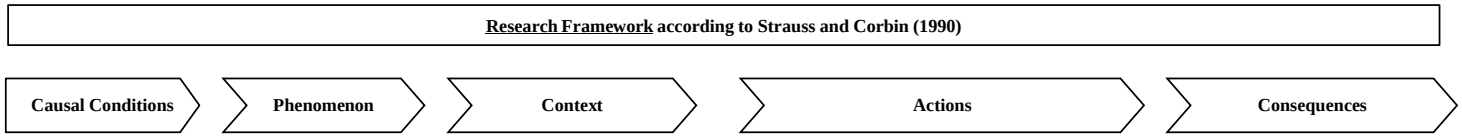

Figure II-1: Research framework for qualitative studies according to Strauss and Corbin (1990).

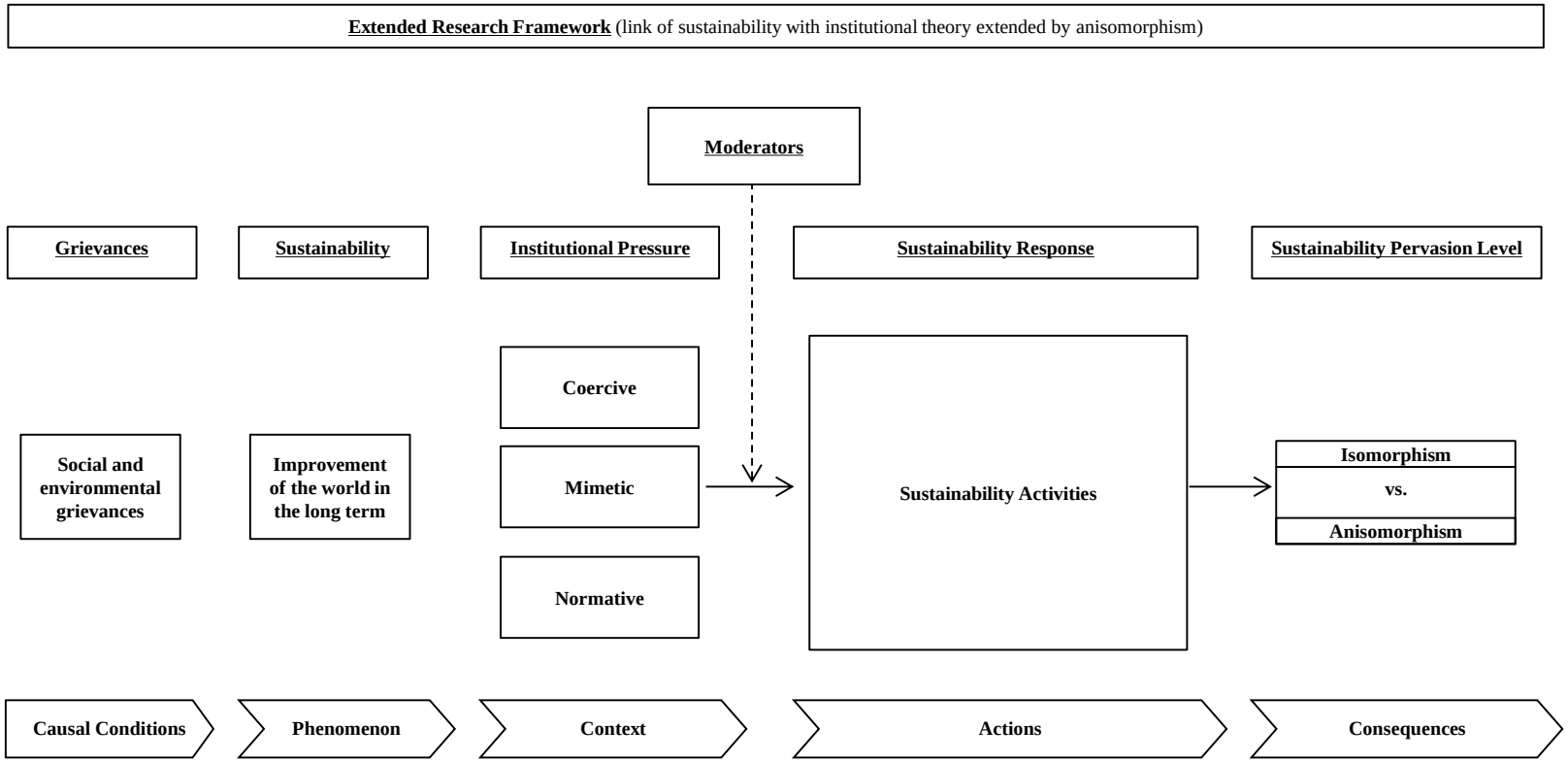

Figure II-2: The extended research framework: Link of sustainability with institutional theory.

3. Research Methodology – Presentation of the qualitative research design, case selection and data collection

The research methodology set up is threefold:

1. Reasons for applying a qualitative research design (instead of a quantitative one) are given.
2. The selection of the eight companies in the multiple case study is presented.
3. The process of the data collection is described.

These steps will be detailed in the following.

3.1.Research Design – Grounded theory by a multiple case study

An inductive multiple case study is chosen in order to explore institutional pressures on companies' sustainability activities and to identify moderators inducing anisomorphism. This qualitative research design seemed to be the most appropriate for the following three reasons: (1) The complex phenomenon under investigation is still at an exploratory stage (Glover et al., 2014) which can be studied in depth by direct interaction of researchers and informants. Moreover, the target of discovering the information-rich knowledge on how companies implement sustainability and which moderators influence institutional pressures can be pursued best by a case study (Mello and Flint, 2009); (2) The definition of sustainability differs in parts in business practice and literature. Therefore, clarification is needed to establish a common understanding of the notion and to ensure content validity (Foerstl et al., 2010); (3) Multiple data sources and different data collection techniques such as personal interviews and publicly available information have been drawn on for data triangulation to reduce bias (Crane, 1999; Gerring, 2007; Gibbert et al. 2008; Yin, 2009). Both within-method triangulation (Crane, 1999) by means of various

interview questions for the same topic and cross-method triangulation (ibid.) by means of multiple data sources have been applied in this study.

An overview of the measures for ensuring internal validity, construct validity, external validity and reliability through the different phases of this case study is provided in Figure II-3.

Research Phase	Validity/Reliability Measures			
	Internal Validity*	**Construct Validity****	**External Validity*****	**Reliability******
Design	• Constructing a theoretical research framework drawn from literature	• Developing constructs based on previous research in the field of institutionalism and sustainability	• Conducting a cross-case study • Description of sampling criteria	• Drawing up a case study protocol • Compiling a case study database
Case Selection	• Arranging theoretical sample criteria recorded in a case study protocol	• Selecting cases based on a link between theoretical conjecture and expected empirical observations	• Assembling information on cases, their specific situations, and the study context	• Selection based on the criteria "impact of institutional pressures " and "embeddedness in sustainability"
Data Gathering	• Paying attention to potential factors that might deliver alternative explanations	• Referring to multiple sources of information • Engaging multiple interviewers	• Comparable data gathering setting in all cases	• Semi-structured interviews through guiding questionaire • Use of a case study database
Data Analysis	• Identifying and matching of patterns • Triangulating multiple data sources • Aligning theoretical and causal logic	• Reviewing case study report drafts by key informants • Compliance with chain of evidence	• n.a.	• Exchange with researcher not directly involved in the data gathering phase • Checking of codes
	** Corresponds to "logical validity", the causal relationship between variables and results*	*** Refers to the quality and operationalization of the concept*	**** Corresponds to "generalizability", the phenomenon could also be seen in other settings*	***** Refers to the absence of random error, the study is transparent and replicable*

Figure II-3: Validity and reliability measures in each research phase (based on Gibbert al., 2008; Yin, 2009).

3.2. Case Selection

A multistep sampling process was applied to determine the cases (Siggelkow, 2007). In a first step, theoretical sample criteria, such as impact of institutional pressures and embeddedness in sustainability, were gathered in a cluster grid. Subsequently, case selection techniques were applied according to Gerring (2007) and Eisenhardt (1989). Blue chip companies were filtered as they experience high institutional pressure to get involved in sustainability due to their outstanding position regarding performance, their legal form as public, market-listed corporations and their company size in terms of turnover and employees. The focus was on German multinational firms listed in the German stock exchange index (DAX) to obtain a sample with homogeneous antecedents in forms of institutional pressures since, for example, coercive environmental and social pressures by laws and regulations differ broadly around the globe. Subsequently, companies both listed and not listed in the DJSI were selected in order to investigate the moderators impacting the outcome of heterogeneous sustainability pervasion levels.

Eleven potential companies were contacted by email and follow-up telephone calls (Dul and Hak, 2008). Finally, eight companies agreed to take part in this study by allowing interviews in different departments and providing additional internal corporate information to achieve theoretical saturation (Strauss and Corbin, 1990). Out of these eight cases, four were manufacturers and four were service providers of which respectively two companies were classified as high performers in terms of sustainability and two as poor performers determined by the criteria listed in the DJSI and further public sustainability related information (Figure II-4). All internal data was affirmed confidential and anonymized treatment. An overview of the eight cases of the multiple case study is given in the Appendix (Appendix-Chapter II 1 and Appendix-Chapter II 2).

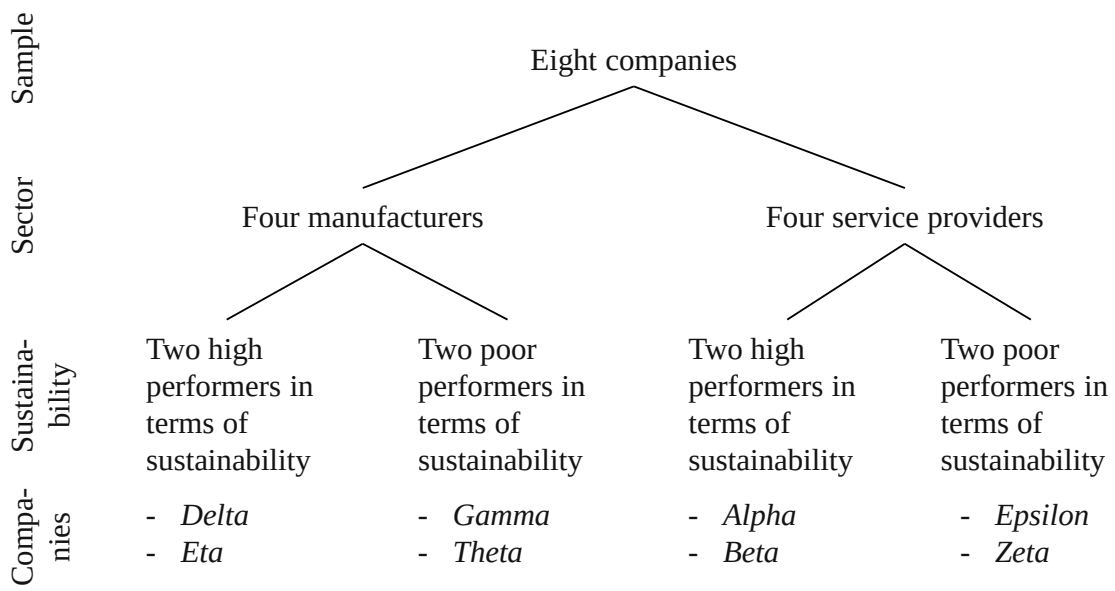

Figure II-4: Selection of the eight companies for the case study sample.

3.3. Data Collection

The primary data collection took place from August 2011 to February 2012[*]. Therefore, a pre-questionnaire was sent to the interviewees to ask them for a brief overview of their company, its sustainability commitment and their personal function within their department. Simultaneously, all publicly available secondary data was collected. For instance, companies' communication material from homepages, annual reports, sustainability reports or press releases as well as third party data, such as media reports, NGO information or sustainability indices' data, was gathered for subsequent triangulation purposes (Gibbert et al. 2008). By combining the self-assessment and the publicly available data, the interview guideline was developed and modified individually for each case (Perry, 1998). Due to this sequential course of action, the particular company situation was considered and certain phrases found in public data could be challenged by questioning them directly in the interviews.

[*] The timelines of data was confirmed by the latest literature (see section 2.)

In the end, 35 relevant key informants from different departments such as Corporate Responsibility (CR), Sourcing, Operations Management (OM), and Marketing as well as with different job positions ranging from assistant managers up to top management were interviewed. In each company at least one responsible top manager from the procurement and CR department was questioned. The semi-structured interviews were executed face to face or via telephone and lasted up to two and a half hours – 75 minutes on average. All interviews were recorded and transcripted immediately, token notes as well as specific circumstances of the interviews were gathered in a case study protocol. The interview transcripts already comprised around 500 pages. All relevant information was compiled in a case database including public data, interview quotes and individual observations (Yin, 2009).

4. Data Analysis and Results

In the previous chapter, the selection of the qualitative research design was motivated and the determination of the investigated cases was presented as well as the process of the data collection. In the following, the performed analyses will be presented and subsequent results depicted.

4.1. Data Analysis

The data analysis of primary interview data and secondary corporate data was conducted in two phases. First, an extensive within-case analysis was realized by coding the interview transcripts and structuring the gathered secondary data. In order to avoid researchers' bias, this iterative process of data analysis was executed by various researchers separately after all data had been collected (Miles and Hubermann, 1994). Subsequently, key categories of firms' sustainability activities could be identified and

classified into the four sub-categories: (1) Employees; (2) Processes; (3) Organization; (4) Business Field.

In a second phase, a cross-case analysis was conducted to discover communalities and differences (patterns) (Eisenhardt and Graebner, 2007) of companies' responses to institutional pressures on sustainability, to determine possible moderators and to investigate the identified constructs by means of Excel tables (Miles and Huberman, 1994). An overview of the cases' sustainability activities is provided in Table II-2. In addition, an excerpt of selected quotes is given in Appendix-Chapter II 4 and Appendix-Chapter II 5.

Table II-2: Sustainability activities of case companies (overview of interview results).

Company	*Alpha*	*Beta*	*Gamma*	*Delta*	*Epsilon*	*Zeta*	*Eta*	*Theta*
Sustainability Actions on:								
Employees	• Health program • Women's quota for top management positions • Connect life & work programs	• Training programs to reduce fuel consumption • Sports initiatives • Voluntary social programs	• Diversity management • Support of social projects • Sustainability integrated in management targets	• Best practices in production conditions • Worldwide health care management • Incentives for sustainability commitment	• Reduction of work accidents • Sabbaticals for social projects • Sustainability training for procurement managers	• Management bonus dependent on sustainability performance • Leave for social volunteering • Employee satisfaction measures	• Anti-corruption & compliance standards • Employee commitment index • Sustainability targets for management	• High labor security standards • Sabbaticals for social issues • Diversity and inclusion programs
Processes	• Renewable energies only • Eco design packaging • Sale of waste as resource • Internal & external Code of Conduct • Regular supplier audits • Sustainability rating of suppliers	• Comprehensive sustainability KPIs • Code of conduct for suppliers • Carbon accounting in fleet policy • Paperless offices • Energy efficient buildings	• Process efficiency • Waste management • Sustainability workshops with suppliers • Long lifespan of machines and products	• Clean production • Water management • Cost saving processes • Environmental management system • On-site audits of suppliers	• Emission reductions • Supplier audits by internal and external reviewers • Risk management system	• Energy savings • Water protection • Corporate Code of Conduct • Suppliers sustainability commitment obligatory	• Eco-efficiency targets • Green building initiative • Sustainability risk assessments of suppliers • Loans for energy efficiency projects	• Process redesign investments • Clean water program • Permanent monitoring of processes • Regular sustainability evaluations of suppliers
Organization	• CR department • Sustainability Officer on board level • Cross-functional sustainability task force • Green travel policy • Sustainability campaigns for customers	• CR department • CO_2 reduction training for customers • Investor relations with sustainability road shows • Cooperation with NGOs • Lobbyist for higher sustainability laws	• CR department • Sustainability board directly linked to board • Creation of customer experience on sustainability • Research alliances for hybrid engines	• CR department • Cross-functional sustainability working groups • Exchange with external stakeholders (e.g. NGOs) • Cooperation with authorities to introduce new standards	• CR department • Proceedings against environmental laws • Appointment of Chief Compliance Officer to the board • Stakeholder management	• CR department • Proceedings against environmental laws • CR-strategy incl. milestones approved by board • Green car policy	• CR department • Chief Sustainability Officer on board level • Promotion of internal sustainability community • Green partnerships across industries • Integrity cooperation with World Bank	• CR department • Appointment of Climate Protection Officer • Cooperation with suppliers to foster sustainability • New sustainability vision installed
Business Field	• Introduction of green products • Rebuy of old products for recycling purposes	• Setup of green business division with sustainable solutions • Green packaging	• Establishment of car sharing as new sustainable business field	• Precursor to new eco-friendly technology	• Sale of division with highest emissions	• Development of renewable energies division	• Sale of nuclear division • Expansion of sustainability products	• Development of new sustainable technologies as substitutions

4.2. Sustainability Responses to Institutional Pressures – Developing a new research model

This study investigates how the three institutional pressures –coercive, mimetic and normative pressures – influence companies' sustainability actions. Therefore, the research model was incrementally developed (Figure II-5). The analysis of the case study reveals that these sustainability actions can be classified into the following sub-categories employees, processes, organization, and business field. However, each of the three pressure types interacts differently with these sub-categories. As a result, isomorphism in terms of average-sustainability pervasion levels can be stated. Hence, three propositions were formulated describing the analyzed phenomenon, as will be presented next.

4.2.1. Sustainability Responses to Coercive Pressure

Coercive pressures by laws and regulations to implement sustainability forces all cases of this study to deal with the subject and align their processes accordingly in order to fulfil legal requirements to a minimum standard. Coercive pressures exist regarding both environmental and social sustainability aspects. Following diverse environmental regulations, the case companies have installed eco-efficiency processes as energy, waste and water management programs to reduce the consumption of resources and to comply with applicable law. All cases record greenhouse gas emissions, publish respective figures and announce reduction targets based on emission trading regulations. Furthermore, in order to act in compliance with social regulations, these firms obey labor laws and safety standards. Additionally, the case companies offer health care programs to foster occupational health and decrease sickness rates (Table II-2).

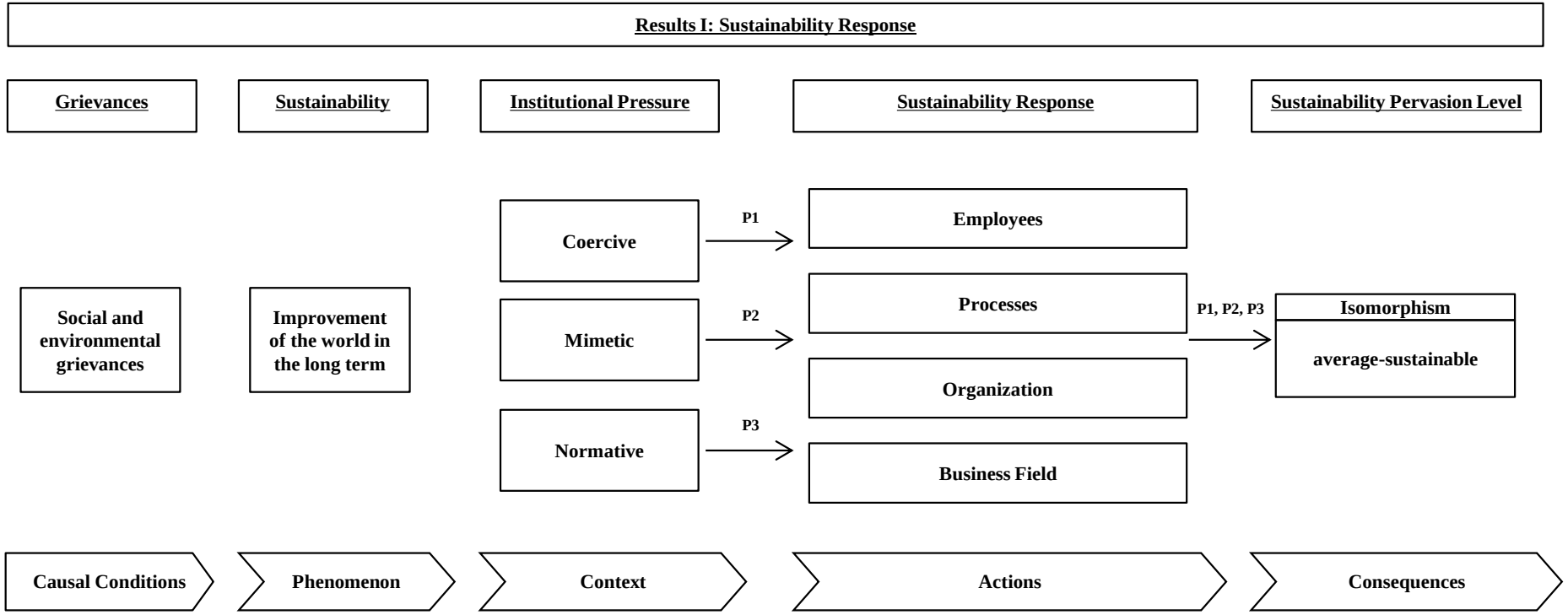

Figure II-5. The developed model (Results I): Sustainability responses to institutional pressures.

To measure their sustainability activities, the eight companies have sustainability KPIs in place in response to coercive pressures exerted by authorities and NGOs (Appendix-Chapter II 3). Accordingly, all cases track their CO_2 emissions and present them divided into scope 1, scope 2, and scope 3 in line with the "Greenhouse Gas Protocol" (GHG) guideline. In addition, *Beta* publishes the number of vehicles with alternative engines in its fleet as an extra environmental indicator. Likewise, the investigated cases publish social activity KPIs such as workplace accident rates (all cases), sickness rates (all cases but *Epsilon*) and share of women in middle and upper managerial positions (all cases).

All companies confirm that they notice the coercive pressures on sustainability activities. Representatively, an executive safety manager at *Theta* states:

> "To generalize, all legislations are supposed to incentivize sustainability activities. There are rules on emission trading, labor security, energy consumption and gender politics *Theta* has to fulfil."

One step further, a CSR manager at *Gamma* demands:

> "Mainly with the support of political decision-makers through the creation of basic standards […] sustainability can advance. In this context, public authorities also have to control and monitor its realization."

All interviewees stress that they comply with legal requirements at least at a minimum level. Thus, coercive pressures create a framework for isomorphic sustainability activities resulting in average-sustainability pervasion levels. This observation is in line with previous research (Boselie et al., 2003; Sayed and Hendry, 2016). Hence, the first proposition is formulated:

Proposition 1. *The higher the degree of coercive pressure on sustainability, the higher the likelihood of greater conformity with this pressure through isomorphic sustainability activities, leading to average-sustainability pervasion levels.*

4.2.2. Sustainability Responses to Mimetic Pressure

Mimetic pressure on sustainability resulting in the adaption of competitors' organizational structures can be observed in the investigated cases. For instance, all cases publish not only annual financial reports, but also regularly launch separate sustainability or CR reports. Likewise, in all considered cases new organizational structures were implemented by installing CR departments with sustainability officers.

Besides mimicry of organizational sustainability structures, mimetic pressure evokes the implementation of similar sustainable processes as well. Initially, however, there are a lot of internal resistances as for example the head of the CR department of *Zeta* admits:

> "With regards to cross-functional cooperation in the context of sustainability, we had to overcome serious conflicts in the past years."

As other companies in the market are increasingly implementing sustainability activities, this mimetic pressure leads companies to change their position as for instance an innovation manager at *Epsilon* expresses:

> "However, our competitors have started to engage in sustainability subjects. Thus, we have to catch up."

Moreover, mimetic pressures not only lead to similar organizational structures and processes, but also impact the fields of business a firm is active in. When competitors discover new opportunities by dealing with the topic of sustainability and thereby creating new business fields for a certain sector, other companies follow and try to enter these new

markets. For instance, case *Gamma* as a car manufacturer has introduced the new business of car sharing. Today, *Gamma* provides a huge fleet for car sharing, in parts even with electric engines. In contrast, competitor *Delta* has just started to engage in the car sharing market after being exposed to mimetic pressures.

When companies are imitating certain sustainability structures on the same levels, a middle field cluster towards sustainability pervasion is formed. Thus, mimetic pressures due to uncertainty produce isomorphic sustainability activities to gain legitimacy even without any proof of added efficiency (Wu et al., 2012). These observations are manifested in the second proposition:

Proposition 2. *The higher the degree of mimetic pressure on sustainability, the higher the likelihood of greater conformity with this pressure (mimicry) through isomorphic sustainability activities, leading to average-sustainability pervasion levels.*

4.2.3. Sustainability Responses to Normative Pressure

Normative pressure on the case companies' sustainability commitment emerges as their managers attend the same training programs on environmental management and business ethics and convey those new ideas to their firms. All of the interviewees participate in several workshops or educational training courses each year where sustainability is discussed. In addition, professional networks and their regular meetings contribute to the prevalence of the sustainability notion which the interviewees also confirm. Moreover, all companies in the sample experience normative pressure exerted by external consultants introducing similar sustainability concepts. The fact that companies' sustainability activities are induced by normative pressures was acknowledged by the head of the sustainability external office at *Eta* who participated at international sustainability conferences:

> ”Especially the participation at the UN climate summit in Cancun, Mexico, was a special event for me. It was very inspiring and made me even more aware of this important and urgent topic. Based on this meeting, I had many new inputs that I implemented in our firm.”

Furthermore, there is also a trend to install horizontal and vertical cooperation regarding sustainability programs. Horizontal cooperation, for instance sustainability research alliance with competitors to develop new technologies (e.g. hybrid engines), is installed as interviewees at *Gamma* and *Eta* confirm. Likewise, vertical sustainability cooperation along the supply chain with customers and suppliers is in place: *Alpha*, *Beta*, *Gamma*, *Delta* and *Theta* explicitly foster external sustainability workshops with suppliers to evaluate the current situation, review audit results and exchange sustainability solutions on a regular basis.

In addition, NGOs as normative institutions demand new social and environmental standards and more sustainability commitment. Accordingly, each of the respondents points out that their company has introduced certain Codes of Conduct, compliance rules or internal sustainability guidelines or has signed optional sustainability compacts such as the UN Global Compact.

Hence, prior studies can be confirmed stating that normative pressures based on social obligations force companies to comply with sustainability through isomorphic behaviors (Glover et al., 2014). Thus, it is proposed:

Proposition 3. *The higher the degree of normative pressure on sustainability, the higher is the likelihood of greater conformity with this pressure through isomorphic sustainability activities, leading to average-sustainability pervasion levels.*

4.3. Moderator "Expected Sustainability Benefits"

In this study, it is explored why institutional pressures on sustainability do not always result in isomorphism impacted by moderators. The concept of anisomorphism is introduced as the opposite phenomenon of isomorphism. To make it more specific, sustainability pervasion levels are established as a measure for isomorphism and anisomorphism, respectively.

There are three classes this essay distinguishes with respect to companies' sustainability realization: First, there are pioneering firms performing on a high (supra) level of sustainability pervasion expressed by a pro-active sustainability commitment spread across the whole organization. Second, there are average-sustainable firms characterized by isomorphic sustainability activities mainly driven by institutional pressures. Third, there are laggard firms with very low (sub) sustainability pervasion levels with tendencies to decline the implementation of sustainability.

Table II-3: Three levels of sustainability pervasion.

Sustainability Pervasion Level	Morphism Category	Definition	Examples
Supra-sustainable	Anisomorphism	Genuine, pro-active sustainability behavior	A firm implements advanced sustainability activities and acts as a role model to drive sustainability forward (cases *Alpha*, *Beta*)
Average-sustainable	Isomorphism	Semi-active to semi-passive sustainability behavior	A firm fulfils minimum sustainability requirements, rather few additional sustainability activities are implemented (cases *Gamma*, *Delta*, *Eta*, *Theta*)
Sub-sustainable	Anisomorphism	Defensive, resistant sustainability behavior	A firm refuses sustainability commitment and is reluctant to implement sustainability activities (cases *Epsilon*, *Zeta*)

In the previous chapter, it was investigated how institutional pressures lead companies to install sustainability yielding isomorphism in terms of average-sustainability pervasion levels. Nevertheless, there are companies that differ defined as anisomorphic. Two moderators responsible for this heterogeneity were identified, i.e. the moderators

“expected sustainability benefits” and “top management support”. Their specific moderating role on institutional pressures within the field of sustainability will be presented in the following.

In the present case study, the first moderator “expected sustainability benefits” was found to be an important force essentially influencing the outcome of sustainability pervasion. The moderator “expected sustainability benefits” is tripartite and includes expected economic, social, and environmental benefits: (1) Economic benefits are determined by positive monetary returns; (2) Social benefits are expressed by more highly motivated employees due to a better working atmosphere within a company behaving socially correctly. Additionally, qualified employees are attracted when certain ethical standards are established as employees prefer employers with a good reputation; (3) Ecological benefits are demonstrated by lower consumption of water, energy or other resources. Thereby, both lower CO_2 emissions and less waste are produced.

Figure II-6 shows the enhancement of the research model by introducing “expected sustainability benefits” and “top management support” as moderators. The moderators’ influence on each of the three institutional pressures and their respective consequences on the sustainability pervasion levels will be described next and adequate propositions will be deduced.

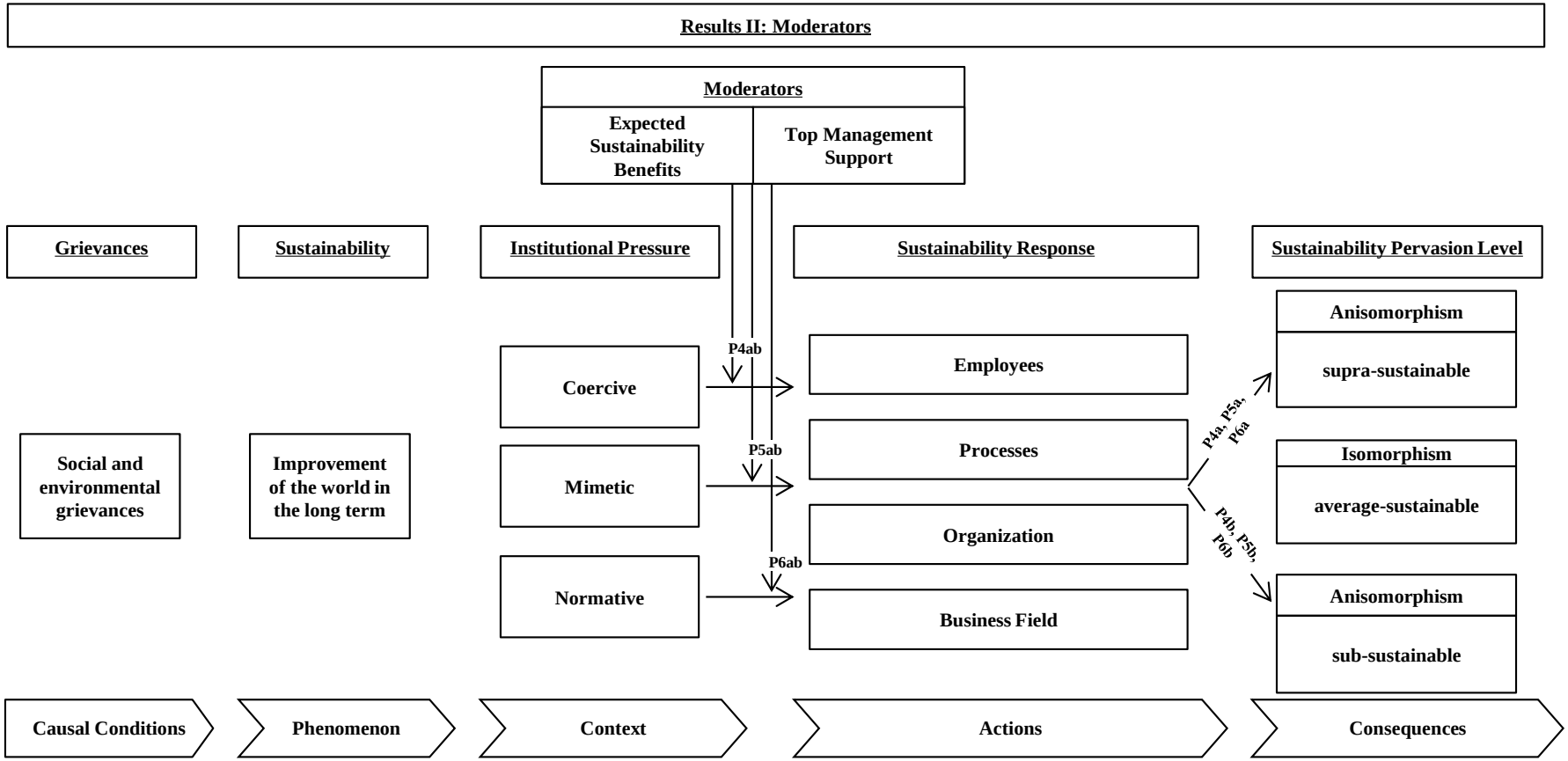

Figure II-6. The developed model (Results II): Moderators of institutional pressures on sustainability.

4.3.1. Coercive Pressure moderated by "Expected Sustainability Benefits"

Coercive pressure leads companies to establish certain sustainability standards, for example through regulations on emissions and emission trading. This could be confirmed by the case companies resulting in isomorphism. However, there are companies outperforming given requirements and standards: *Beta* does not only fulfil given legal environmental requirements, moreover it establishes new zero emission services for its customers. Therefore, *Beta* invests in sustainability projects all over the world which both support people socially and reduce officially certificated emissions. This is a classic win-win-win-situation based on the TBL definition of sustainability. In addition, a new business model is generated in two ways, as firstly a new product is developed and secondly a new investment opportunity has been discovered. An executive manager, responsible for the procurement strategy at *Beta*, stated:

> "Customers have an increased interest in environmentally friendly products. Therefore, we need certain environmental certificates. Hence, we additionally invest in green projects such as wind energy parks in China, waste incineration plants in Turkey or efficient household appliances in Africa. Through these activities, we improve people's lives and help reduce emissions. As a result, we obtain certain CO_2 certificates, so we can offer zero emission services to our customers. It's a real business model."

Likewise regarding coercive pressures on social issues there are companies which go beyond the legally demanded social requirements: As first DAX-listed company in Germany, *Alpha* has introduced a women's quota of 30 percent for women in top management positions, such as on the board of directors and the supervisory board. By doing so, *Alpha* is a clear forerunner compared to the cases in the sample and established

the quota internally long before it was obligatory by German law. A marketing executive at *Alpha* explained:

> "As the market leader in Germany and one of the big players in Europe, we have the responsibility to push topics such as sustainability. I believe we are a pioneer in sustainability, as the introduction of a women's quota shows. Through our initiative, a broad discussion on the quota has started across all levels of society."

Moreover, there are companies that actively push the enactment of higher sustainability standards. This lobbying practice is pursued by *Beta*: *Beta* calls for more coercive pressures by laws on sustainability. Thereby, *Beta* aims at achieving competitive advantages as it already fulfills the demanded sustainability standards and thus would not have additional implementation cost or time lags.

The moderator "expected sustainability benefits" was identified and its impact on coercive pressures and sustainability activities explored. This result is supported in the literature: Glover et al. (2014) have elaborated on the alignment of competing logics of institutional pressures and expected benefits. Hence, the next proposition is derived:

Proposition 4a. *A high level of positive expected benefits from sustainability moderates coercive pressure through anisomorphic sustainability activities, resulting in supra-sustainability pervasion levels.*

Vice versa there are negative expected benefits which influence the outcome of coercive pressure decisively. Negative expected benefits of sustainability, e.g. in terms of higher investment costs, moderate coercive pressures in such a way that certain standards are not fulfilled or only half-heartedly implemented resulting in sub-sustainability pervasion

levels. For instance, an executive product manager at *Epsilon* admits that social activities such as cultural funding is mainly done for corporate image reasons with a certain green-washing tendency. The key focus remains on return, optimization of investments and reduction of input as resources. Furthermore, *Epsilon* openly offers resistance to coercive pressure towards sustainability as it expects negative returns through this commitment. The same is valid for the behavior of the competing company *Zeta* which has filed a suit against certain environmental regulations.

In addition to expected direct negative returns of sustainability commitment, further costs are anticipated. For example, massive resistance by citizens against constructions required for more renewable energy result in court cost and cost of delay as a product manager at *Epsilon* points out:

> ”Regarding the network construction, there are strong regulations by the federal network agency on the one hand. On the other hand, there is resistance by the population especially to new power cable constructions above ground. These conflicts e.g. with citizens’ initiatives substantially impede those investments. For instance, planning for new network construction was done in 2002, but extensive approval procedures and court decisions deferred everything so that construction could not start until 2011.”

Based on the outlined impact of negative expected sustainability benefits on coercive pressures, the next proposition is formulated:

Proposition 4b. *A high level of negative expected benefits of sustainability moderates coercive pressure through anisomorphic sustainability activities, resulting in sub-sustainability pervasion levels.*

4.3.2. Mimetic Pressure moderated by "Expected Sustainability Benefits"

As shown in the previous section, mimetic pressures on organizational structures lead to isomorphism and average-sustainability pervasion levels (see proposition 2). By identifying the moderator "expected sustainability benefits", anisomorphism in terms of supra- or sub-levels of sustainability pervasion is explained. Positive expected benefits moderate mimetic pressures by increasing a firm's willingness to adopt structures and cross-functional boards in such a way that the issue of sustainability can be treated holistically by diverse departments in an efficient and effective way finally leading to supra-sustainability pervasion levels as observable at *Alpha* and *Beta*. *Alpha*, for instance, has installed a so-called sustainability officer at board level and has implemented several cross-functional sustainability task forces to foster sustainability pervasion within the company.

Driven by mimetic sustainability trends all over the market and in expectations of positive benefits, *Alpha* had launched a new sustainable product as an executive explained:

> "As example for our genuine sustainability realization I want to mention the following: Two or three years ago […], we tried to launch a mobile phone with sustainability aspects as its USP. It was based on solar cells as accumulator and the whole package was 100 percent recyclable. Despite that, this mobile phone was no market success, customers simply did not want that kind of product at that time."

Although the positive expected sustainability benefits were not achieved by *Alpha*, it shows that these expectations impact mimetic pressures to establish new organizational structures or enter new markets. The relation of a good public reputation as a mimetic driver linked to expected benefits has been investigated in other contexts in the literature (Glover et al., 2014). Thus, the following proposition is deduced:

Proposition 5a. *A high level of positive expected benefits from sustainability moderates mimetic pressure through anisomorphic sustainability activities, resulting in supra-sustainability pervasion levels.*

Contrariwise, there are negative expected benefits from sustainability that mitigate mimetic pressures as well. For instance, many departments of *Epsilon* are skeptical towards benefits drawn from sustainability. This negative attitude results in a difficult relationship between the departments that pursue each their individual functional interests instead of aligning sustainability targets on a corporate level. Moreover, a manager at *Epsilon* confirmed that mainly due to mimetic pressures, the company would be involved in social activities such as support for cultural institutions, whereas in the technical area, these pressures would be impacted by three expectations on sustainability benefits, i.e. maximization of return, optimization of investments and minimization of resources.
Likewise, the influence of negative expected sustainability benefits can be confirmed by the statement of an executive procurement manager at *Zeta*:

> "Yes, sustainability is an issue gaining more and more in relevance. However, we have to think about ourselves first and by engaging in sustainability we would have to abandon other more profitable fields of business and to instead invest huge amounts of euros to build up a less lucrative business segment."

Although there are trends at *Epsilon* and *Zeta* to do more business in sustainability related fields to follow mimetic pressures, the high level of negative expected sustainability benefits is dominating. As a consequence, in both cases there is resistance to sustainability resulting in sub-sustainability pervasion levels as the next proposition states:

Proposition 5b. *A high level of negative expected benefits from sustainability moderates mimetic pressure through anisomorphic sustainability activities, resulting in sub-sustainability pervasion levels.*

4.4. Moderator "Top Management Support" – Impact on normative pressure

Besides the moderator "expected sustainability benefits", the second moderator "top management support" could be determined. Top management serves as an institutions' key interface to its external environment and is connected to normative pressures (Liang et al., 2007). Top management commitment, expressed for example by sustainable role model behavior, is a strong indicator for the genuine sustainability activities of a firm. This is confirmed by the following quote of an executive in the marketing department at *Alpha* with its supra-sustainability pervasion levels:

> "All other marketing projects had to suffer from budget cuts except our sustainability campaign as this subject is a special concern of our CEO and is therefore supported explicitly by himself."

A strong personal commitment of the CEO himself as well as his support in internal and external sustainability matters was attested independently by other interviewees at *Alpha*. Similarly, managers at *Beta* confirmed top management commitment regarding sustainability aspects in their firm. Following that notion, a carbon accounting manager at *Beta* explained:

> "Sustainability is linked with the idea of a respectable merchant represented by the CEO. You should only do things which you want to read in the newspaper about you, namely to act socially conscious and to work efficiently."

Interestingly, even in case of a high likelihood of negative economic results from engaging in sustainability, positive top management support for sustainability had a stronger influence resulting in supra-sustainability pervasion levels.

The identified moderator "top management support" enhances the present institutional theory and is supported in previous literature: Schaefer (2007) has defined top management concern as an institutional factor and Zhu et al. (2008) have described the commitment of the top and mid-level management as critical for green activities. Lozano (2015) has shown that pro-active leadership is one of the most crucial drivers for corporate sustainability. In line with that notion, Liang et al. (2007) have investigated that top management beliefs can have a mediating role regarding the implementation of certain programs such as sustainability activities. Thus, the next propositions is derived:

Proposition 6a. *A high level of positive top management support for sustainability moderates normative pressure through anisomorphic sustainability activities, resulting in supra-sustainability pervasion levels.*

Conversely, support was found that a strong negative attitude among the top management may lead to the refusal of sustainability implementation resulting in sub-sustainability pervasion levels: The CEO of *Zeta* had declared in public his concerns against certain sustainability laws and in particular against renewable energies. The statement of the top manager was followed by a lawsuit of *Zeta* against these sustainability regulations.

As the counterpart to Proposition 6a, the final proposition is formulated:

Proposition 6b. *A high level of negative top management support for sustainability moderates normative pressure through anisomorphic sustainability activities, resulting in sub-sustainability pervasion levels.*

5. Contributions and Future Research

This essay has studied how companies respond to institutional pressures on sustainability and how moderators impact the degree of sustainability pervasion. Based on the case study with eight multinational companies, there are three main academic contributions.

First, companies' responses to institutional pressures were elaborated by presenting their sustainability activities. The responses were classified into four sub-categories, i.e. employees, processes, organization, and business field. Thereby, in-depth insights on how companies respond to coercive, mimetic, and normative pressures were delivered. Moreover, the call of Ashby et al. (2012) was considered and a new research model introduced which reveals sustainability responses to institutional pressures (Figure II-5).

Second, the moderators "expected sustainability benefits" and "top management support" were identified to impact institutional pressures on sustainability. Coercive and mimetic pressures were moderated by positive respectively negative expected sustainability benefits. Normative pressures were impacted by positive respectively negative top management support. These results contribute to the academic literature and extend previous studies (Glover et al., 2014; Liang et al., 2007; Lozano, 2015).

Third, the concept of anisomorphism was introduced as the counterpart to isomorphism and three levels of sustainability pervasion as outcome of institutional pressures on sustainability were determined: Supra-, average-, and sub-sustainability pervasion levels. In addition, a new research model was developed and six main propositions were presented (Figure II-5, Figure II-6).

From a practical perspective, there are also several contributions. As some of the interviewees stated, it is crucial that the implementation of sustainability standards is controlled by external auditors such as government officials. Furthermore, politics can drive sustainability by establishing certain benefits from sustainability implementation, e.g. government subventions and tax rebates.

Referring to the identified impact of top management support, it is essential that relevant decision makers are genuinely convinced of their companies' sustainability engagements and foster their sustainability pervasion. In order to properly evaluate the expected sustainability benefits, a holistic consideration of economic, green, and social benefits is required. Finally, companies have to recognize the vast business opportunities arising from sustainability. Accordingly, some of the case companies have already discovered new business fields and developed new products based on the concept of sustainability.

In this study, the case companies were selected from the manufacturing and the service providing sectors with headquarters in Germany. Future studies might extend the study and investigate the impact of institutional pressures on sustainability in other sectors and countries. Thereby, differences in coercive pressures, such as sustainability regulations, and normative pressures, such as societal attitude towards sustainability, might be explored. Last, future research might also test the presented propositions in a quantitative study.

III. Towards Integrated Sustainable Supplier Selection with the Total Sustainability of Ownership Method*

Abstract

Sustainable supplier selection has become a major issue in academic research and business practice. However, there are inherent challenges in genuine sustainable supplier selection considered in the presented paper: Multiple decision-makers with opposing perspectives have to evaluate multiple sustainable selection criteria and measure suppliers' sustainability performances in multiple units.
Based on the concepts of AHP and TCO, we have developed the total sustainability of ownership (TSO) method, which links subjective departmental perspectives with the multi-dimensional objective sustainability performance measures of suppliers. This practical model for sustainable supplier selection was assessed in a multiple case study applying our AHP model with three multinational high-tech firms. The contribution of this paper is twofold: First, it presents in-depth insights on how diverse departments evaluate sustainable sourcing criteria. Second, it proposes an enhanced quantitative model to determine the most sustainable supplier as selected by multiple potentially conflicting decision-makers considering multiple performance criteria measured in different units.

Keywords: *Sustainable supplier selection; multiple decision makers; supplier performance measures; analytic hierarchy process; total cost of ownership; multiple case study.*

* This essay is co-authored by Kai Förstl.
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1. Introduction – Need for a practical sustainable supplier selection model

Sustainable supplier selection is crucial for business success: When integrated in sourcing decisions, sustainability, i.e. defined as the balance of economic, ecological, and social aspects (Elkington, 1998; Kleindorfer et al., 2005), can increase corporate performance, reduces operational risks and contributes to the overall economic success of the firm (Campbell, 2007; Cegarra-Navarro et al., 2016; Dubey et al., 2016; Schaltegger, 2011). Accordingly, suppliers should be selected based on a consideration of all three sustainability aspects instead of considering economic performance alone (Brandenburg et al., 2014; Lueg and Radlach, 2016).

In recent years, the notion of sustainable supplier selection has attracted increasing attention from academic researchers and practitioners (Dubey et al., 2016; Turker and Altuntas, 2014). As a central decision, supplier selection determines a firm's sustainability (Johnsen et al., 2017). These sustainable sourcing decisions are complex that have to be solved by means of models and tools (Brandenburg et al., 2014; Greco et al., 2013). Yet, the lack of a prevalent use of the existing models for sustainable supplier selection in business practice underlines the demand for more practically applicable decision support models (Székely and Knirsch, 2005; Ulutas et al., 2016). In addition, a recent review of papers related to the object of sustainable supplier selection by Zhang et al. (2015) points to a need for a supplier selection model that does not only integrate green or economic criteria, but comprehensively embraces the entire concept of sustainability taking into account suppliers' economic, environmental, and social performances. Furthermore, a practical approach for systematical, joint assessments of quantitative and qualitative sustainability measurements is missing in literature (Ulutas et al., 2016).

Therefore, this paper presents a model for supplier selection which comprehensively integrates the concept of sustainability through performance criteria weights and performance measures based on an analytical hierarchy process (AHP) that is directly applicable in different industries.

In business practice supplier selection decisions often take place as follows: First, there are objective facts depicting each supplier's specifics which are used to compare the suppliers' performances. Second, there are subjective preferences of the involved decision makers which are in favor of specific suppliers. In the present paper, we follow the call of Orji and Wei (2014) and develop a practical model that integrates subjective and objective criteria for sustainable supplier selection and seeks to objectify decision makers preferences based on utility weights derived from the AHP method.

In supply chain management, "one of the greatest challenges […] is the need to embrace sustainability" (Johnsen et al., 2017). In our paper, we consider three problems that arise in the context of practical sustainable supplier selection: The first problem exists due to the participation of multiple decision makers in sustainable supplier selections. These decision makers from various departments are necessary to deal with the increased complexity of sourcing decisions since they represent diverse perspectives and forms of expertise (Taticchi et al., 2015). However, conflicts arise as multiple decision makers partly pursue opposing objectives and demand misaligned requirements and goals that suppliers have to fulfil (Stanczyk et al., 2015). In particular, the issue of sustainability is often considered differently and divergent valuations of economic, ecological, and social criteria lead to serious cross-functional conflicts (Hahn et al., 2015; Reuter et al., 2012;

Taticchi et al., 2015). To optimize corporate performance, it is necessary to erase cross-functional conflicts by aligning procurement departments' targets with other departments' targets (Foerstl et al., 2013; Hochrein et al., 2017). In summary, multiple decision makers often evaluate multiple supplier selection criteria differently especially with regard to sustainability.

A second problem in sustainable supplier selection emerges due to the multi-dimensionality of sustainability and the resulting selection criteria that are in parts conflictive in managerial reality. Traditional sourcing criteria are enhanced through efficiency improvements (Azadi et al., 2015). Consequently, environmental and social sustainability criteria, such as resource consumption, waste management, and labor conditions, complete the traditional economic criteria like quality and price (Amindoust et al., 2012; Turker and Altuntas, 2014). Nonetheless, multiple criteria add further complications with regard to the supplier selection because there trade-offs between the three sustainability dimensions on various levels may occur (Brix-Asala et al., 2016; Hahn et al., 2015). On a major level, environmental, social, and economic objectives can be opposed, e.g. environmental criteria such as low emissions may hinder financial criteria as a low purchase price in the short-term. On a sub-level, the sub-criteria in each of the three sustainability perspectives can be conflictive, e.g., from the economic perspective, cost targets may exclude quality standards. In business practice, decision makers often face these conflicts in sustainability and thus have to manage the trade-offs of sustainability criteria. In summary, multiple, heterogeneous selection criteria that integrate the object of sustainability are difficult to fulfil in parts simultaneously, and therefore have to be ranked by relevance for supplier selection purposes.

The third problem in sustainable supplier selection decisions arises as there seems to be a lack of implemented measures for suppliers' sustainability performance (Bhattacharya et al., 2014; Dubey et al., 2016; Tacchichi et al., 2015). Some criteria, such as purchase price, can be easily used to measure and compare suppliers. However, ecological and social criteria are more difficult to determine and quantify. For example, the assessment of suppliers' greenness level or corporate social responsibility is not trivial. Moreover, even in the case of measurement options, there might be different, non-comparable metrics. For instance, purchase price, as determined in monetary units, cannot be compared directly to emissions calculated in weight units. Thus, we refer to the call for holistic sustainability measures by Tacchici et al. (2015) and face the problem of developing performance measurements for suppliers' sustainability level with multiple metrics.

Hence, we consider three problems to be integrated in our practical approach for sustainable supplier selection. To depict the complex situation, we have developed a conceptual model (Figure III-1).

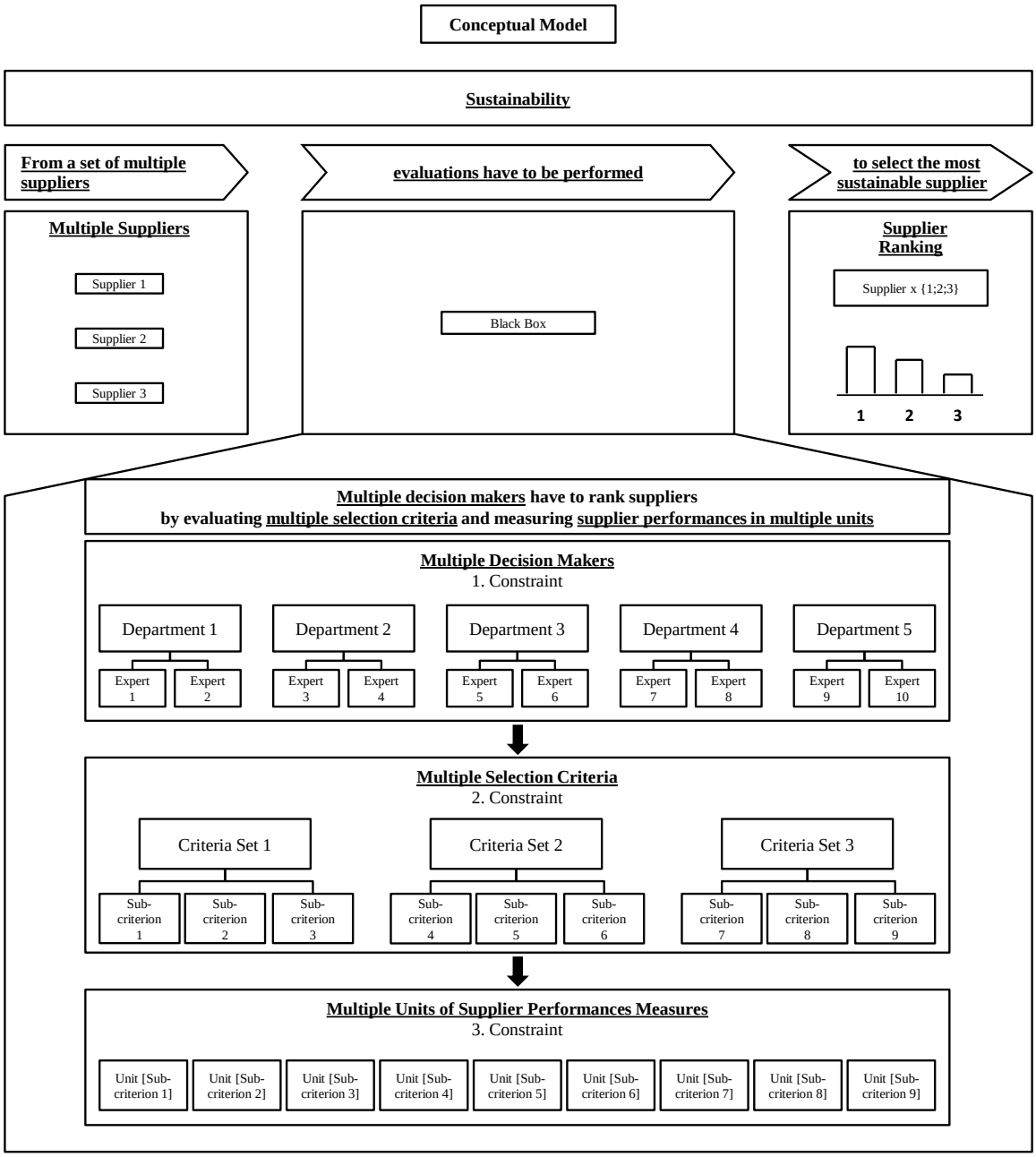

Figure III-1: Conceptual model: Sustainable supplier selection under three constraints.

The remainder of this paper is structured as follows: First, we review the recent literature on sustainable supplier selection models and measurement methods of suppliers' sustainability performance with a focus on applicability in business practice. Next, we develop a quantitative model and present our mathematical methodologies. To validate our model, we conduct a scenario-based pre-test with experts, followed by a multiple case

study in the high-tech sector. Finally, we analyze our results and conclude the paper with academic and managerial implications.

2. Literature Review

2.1. Literature Review on Quantitative Sustainable Supplier Selection Models

In literature, decision making has been investigated under diverse constraints and from different perspectives (Eranova and Prashantham, 2016). Thereby, sustainable supplier selection has been studied as a central decision of sustainable supply chain management (SSCM) (Zhang et al., 2014). Consequently, conceptual and quantitative models have been developed, albeit to a different extent: Quantitative models serve as a research subject of about 10 percent of the SSCM papers only (Brandenburg et al., 2014; Fahimnia et al., 2015). These quantitative models incorporate, for instance, multiple criteria decision-making (MCDM) techniques, mathematical programming (MP) techniques and artificial intelligence (AI) techniques (Chai et al., 2013; Govindan et al., 2015; Ho et al., 2011). Moreover, integrated approaches for supplier selection have been evolved that combine individual methods, such as an AHP-Entropy-TOPSIS method for green supplier selection (Freeman and Chen, 2015), a DEMATEL-TOPSIS method for sustainable supplier selection (Orji and Wei, 2014) and an AD-AHP method for the selection of transportation suppliers (Zhang et al., 2014). Fuzzy models are another variation that reflect the uncertainty of evaluators by use of linguistic variables (Chai et al., 2013).

The analytic hierarchy process (AHP) method is one of the most used MCDM methods in literature (Chai et al., 2013; Ishizaka, 2014). Developed by Saaty in the 1970’s, the AHP method determines quantitative weights for mostly qualitative criteria based on

subjective evaluations of decision makers (Kubicz et al., 2015; Saaty, 1990). Thereby, a complex decision problem can be solved by definition of a hierarchy of (sub-)goals, determination of evaluation criteria and assessment of alternatives in a structured way (Deng, 2017).

Even though in academic papers the AHP method has been proven to be a useful tool, there is a lack of its diffusion in business practice such as in supplier selection problems (Ulutas et al., 2016). Moreover, there are often inconsistencies in the evaluators' pairwise criteria assessments – measured by the consistency ratio (CR) – that leads to a revision of the whole evaluation (Deng, 2017; Greco et al., 2013; Ishizaka, 2014). Thus, there is a need for a novel, more simple AHP method that delivers higher consistency rates we want to develop.

In addition, there are some inadequacies in existing studies on sustainable supplier selection as Orji and Wei (2014) note. First, the main SSCM models focus on the environmental dimension and do not integrate all three sustainability dimensions holistically as recent reviews of the sustainable supply chain management literature with a focus on quantitative models reviews have identified (Brandenburg et al., 2014; Zhang et al., 2015; Lueg and Radlach, 2016; Taticchi, 2015). Second, Zhang et al. (2014) and Taticchi (2015), among others, call for further research on frameworks and tools for performance measures of ecological and social issues within SCM such as the performance measure of suppliers' sustainability level. Third, as Taticchi (2015) and Ulutas et al. (2016) recognize, there is a need for empirical research, e.g. by use of

quantitative models, to close the gap between existing models in academic papers and their implementation in business practice.

In summary, we consider these three issues in the present paper: First, we embrace all three sustainability dimensions; second, we develop an approach that determines performance measures of suppliers' along the three dimensions of sustainability; and, third, we present a quantitative model for use in the industry.

2.2. Literature Review on Suppliers' Sustainability Performance Measures

In literature, there have been developed some methods for suppliers' sustainability measures such as a fuzzy multi-criteria approach (Govindan et al., 2013) and life cycle cost assessments (Zhang et al., 2014; Eskandarpour et al., 2015). Thereby, the total cost of ownership (TCO) concept is a well-known approach to determine supplier performances with focus on the economic dimension of sustainability (Chai et al., 2013; Ellram 1995; Ho et al., 2010): The TCO concept considers all costs associated with the purchase of a product or service (Degraeve et al., 2000; Ellram 1993; Ellram and Siferd, 1998).

However, there is a need for sustainability performance measures and metrics in SSCM as Dubey et al. (2016) identify in their literature review. Even though some measurement methods have been developed, there is a lack of commonly used measures (Ahi and Searcy, 2015). Moreover, there is no generic assessment method for comparing the different metrics that are necessary to capture the sustainability performance of suppliers

comprehensively (Taticchi, 2015). This again demonstrates the complexity of the subject of sustainability performance measures as Eskandarpour et al. (2015) note.

In addition, the measurement of suppliers' sustainability performance is crucial but challenging in business practice: Hitherto, there is a lack of implementation of sustainability measures in the industry (Zhang et al., 2014; Taticchi, 2015). Especially a prevalent use of the TCO approach in business practice is limited, mainly due to its intricate calculations (Visani et al., 2016). As Székely and Knirsch (2005) suggest, we introduce a new practical model to measure and compare suppliers` sustainability performances to select the most sustainable supplier. Therefore, we develop a method that enables the measurements of sustainability criteria and that facilitates comparisons among them.

3. Model Development

We develop a two-level sustainable supplier selection model (level 1: subjective evaluations; level 2: objective measures) in Figure III-2: First, sustainable selection criteria are determined and, second, weighted by multiple decision makers by use of our advanced AHP method with novel elements (subjective evaluations). Third, measures for suppliers' sustainability performances are defined, and, fourth, applied using inverse metric calculations based on our notion of Total Sustainability of Ownership (TSO) (objective measures). Fifth, both steps are combined resulting in a supplier ranking to select the most sustainable supplier. This integrated AHP-TSO method is presented in detail in the next two sub-sections.

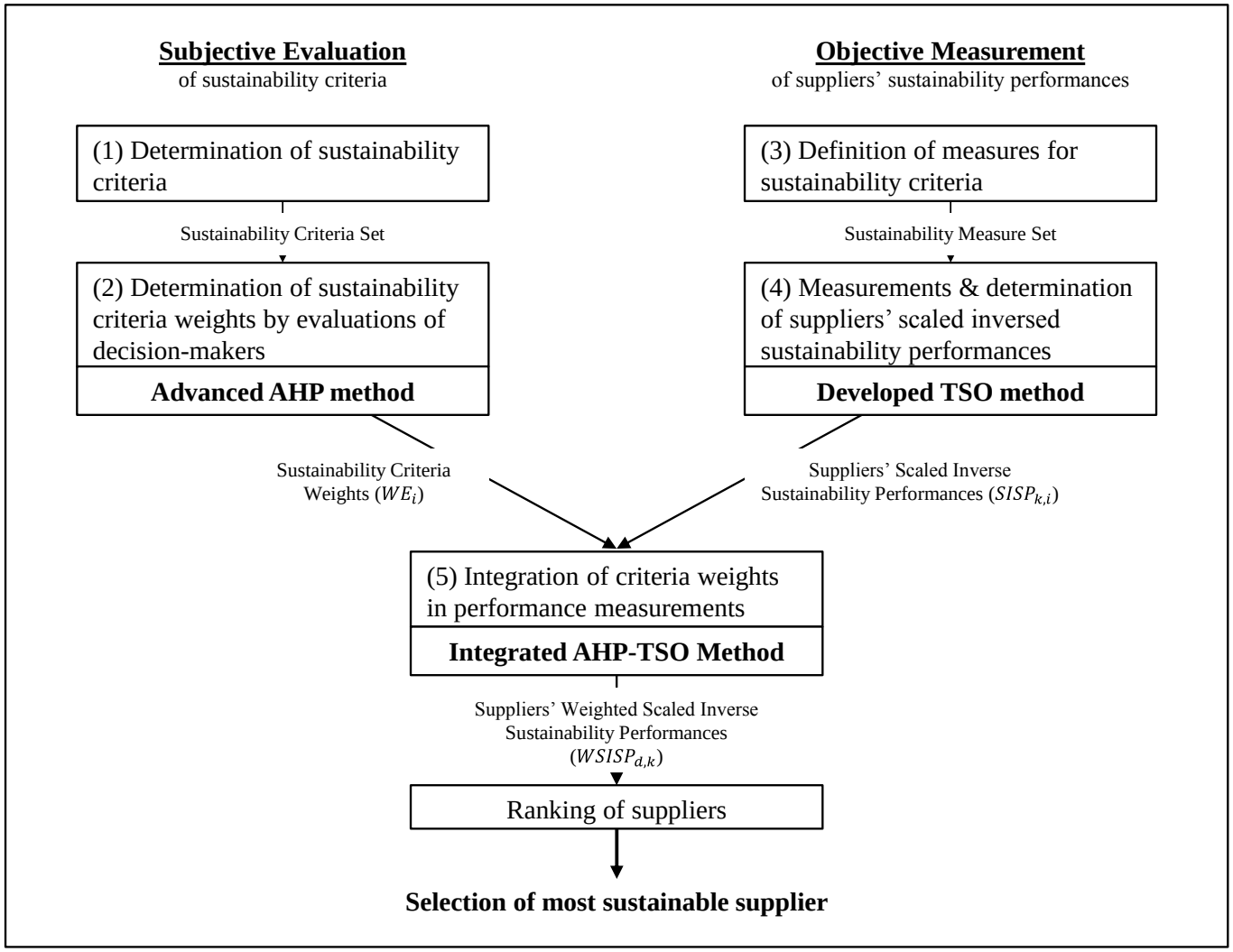

Figure III-2: Integrated AHP-TSO Method: Combining subjective evaluations and objective measurements.

3.1. Development of a Novel, More Simplistic AHP Method for Sustainability Criteria Weighting

We enhance the AHP method and its five phases in essential parts for a more practical use in the context of sustainable supplier selection as described in the following.

3.1.1. Definition of Target and Sustainability Criteria

The first phase of the AHP method is the definition of the overall target (level 1). The intention is to select the most sustainable supplier and reach a sourcing decision on a corporate level involving both sustainability and long-term profitability concerns. We designate this aspired goal with the name of our sustainable sourcing model, i.e. the "Total Sustainability of Ownership" (Figure III-3).

In the second phase, a hierarchy of sub-goals is constructed by definition of criteria and sub-criteria and determination of decision alternatives. Predicated on the triple bottom line (TBL) sustainability approach by Elkington (1994), our sub-goals are specified in three criteria as environmental, economic, and social (level 2). We consecutively classify nine relevant sustainability sub-criteria (level 3) by deriving them from recent literature (Bhattacharya et al., 2014; Ishizaka, 2014; Sarkis and Dhavale, 2015; Yawar and Seuring, 2015; Zorzini et al., 2015). The selected sustainability sub-criteria are as follows: Emissions, energy, and waste to specify the environmental dimension (Bai and Sarkis, 2010; Zhu and Sarkis, 2004); price, quality, and time to specify the economic dimension; (Bai and Sarkis, 2010; Bilbao-Terol et al., 2012; Chan et al., 2008; Ferrin and Plank, 2002; Krause et al., 2001; Székely and Knirsch, 2005; Zhu and Sarkis, 2004); security, code of conduct, and compliance to specify the social dimension (Ayag, 2007; Bai and Sarkis, 2010; Székely and Knirsch, 2005; Turker and Altuntas, 2014). It has to be noted

that firms can easily replace the sub-criteria depending on their most important sustainability criteria. Finally, we list the alternative suppliers below (level 4).

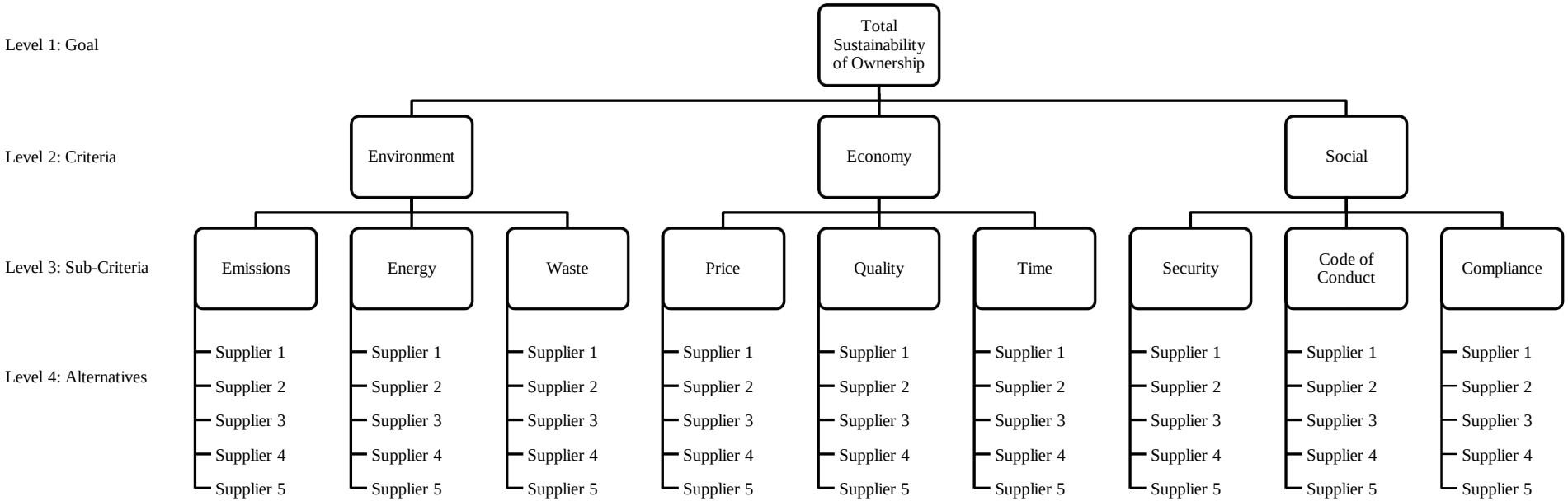

Figure III-3: Total sustainability of ownership: Definition of goal, criteria, sub-criteria and alternatives (first and second AHP phase).

3.1.2. Introduction of a New AHP Comparison Center

Phase 3 presents the key part of the AHP method: The decision makers have to perform pairwise comparisons for the given n sustainability criteria (Greco et al., 2013). In the classical AHP method, an evaluation scale from 1 to 9 is used, with 1 implying the two criteria compared are equally important and 9 implying the second criteria under comparison is considerably more important.

However, there are some well-known problems with this scale as Ishizaka (2014) depicts. For example, the 1-to-9 scale with the non-intuitive center of 1 is difficult to understand and evokes resistance by practitioners for actual use (as we can confirm by our case study presented in the next section). Therefore, we develop a scale from -9 to +9, with the new center of zero as equal relevance point*. To make it even more intuitional, we present the scale graphically in the design of a slider (Figure III-4).

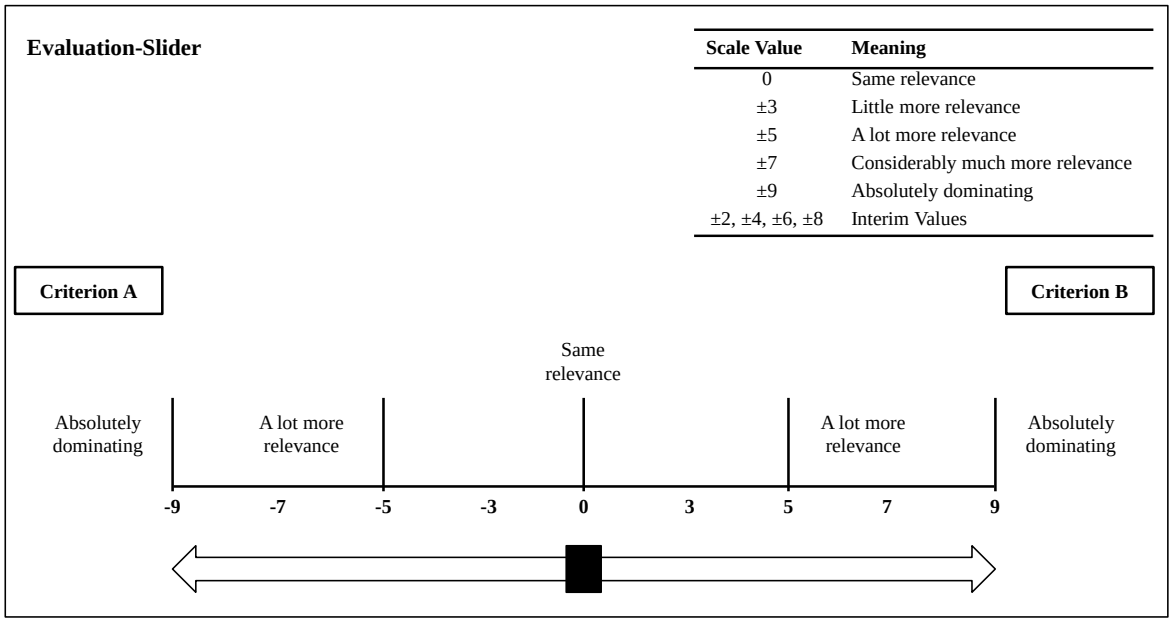

Figure III-4: Development of the AHP method: Enhancement of the evaluation scale with new center.

* For mathematical reason, we automatically transfer the assessments to the scale 1 to 9 for subsequent calculations in the used tool.

3.1.3. Development of Transitive AHP Evaluations

A likely reason for the lack of distribution of the considered MCDM method is the considerable effort by the high number of assessments: In the classical AHP method, $\frac{n\times(n-1)}{2}$ evaluations have to be performed with n representing the number of criteria. Applied to our conceptual model with n=9 sustainability criteria, 36 pairwise criteria comparisons had to be completed – by each decision maker.

For a novel, more simple AHP method, we introduce transitive evaluations, i.e. the application of consistency logic mathematically implemented within the evaluation matrix.

New formula for transitive evaluations:

$$E_{r,s} = \frac{E_{r_{fixed},s}}{E_{r_{fixed},r}}$$

Table III-1: Definition of the element evaluation value and weighted evaluation value.

Element	Indices	Explanation
$E_{r,s}$	$r = 1 \dots n$ $s = 1 \dots n$	Evaluation value E of the criterion in row r in column s in a nxn matrix with n criteria; $E = \{\frac{1}{9}, \frac{1}{8}, \frac{1}{7}, \dots, 1, \dots, 7, 8, 9\}$
WE_i	$i = 1 \dots n$	Weighted evaluation value, determined by the eigenvector of the normalized evaluation values matrix; final weight for the criterion C_i

In the present paper, we determine nine sustainability criteria. Accordingly we consider a 9x9 AHP comparison matrix. The diagonal values are set as one by definition as a criterion compared with itself has to be evaluated with the same importance. The values below the diagonal are defined as reciprocals of the values over the diagonal. Thus in the classical AHP method, all values over the diagonal have to be determined by pairwise

comparison by each decision maker – these are in total the mentioned 36 assessments in our study (Figure III-5).

$$\begin{bmatrix} 1 & E_{1,2} & E_{1,3} & E_{1,4} & E_{1,5} & E_{1,6} & E_{1,7} & E_{1,8} & E_{1,9} \\ \frac{1}{E_{1,2}} & 1 & E_{2,3} & E_{2,4} & E_{2,5} & E_{2,6} & E_{2,7} & E_{2,8} & E_{2,9} \\ \frac{1}{E_{1,3}} & \frac{1}{E_{2,3}} & 1 & E_{3,4} & E_{3,5} & E_{3,6} & E_{3,7} & E_{3,8} & E_{3,9} \\ \frac{1}{E_{1,4}} & \frac{1}{E_{2,4}} & \frac{1}{E_{3,4}} & 1 & E_{4,5} & E_{4,6} & E_{4,7} & E_{4,8} & E_{4,9} \\ \frac{1}{E_{1,5}} & \frac{1}{E_{2,5}} & \frac{1}{E_{3,5}} & \frac{1}{E_{4,5}} & 1 & E_{5,6} & E_{5,7} & E_{5,8} & E_{5,9} \\ \frac{1}{E_{1,6}} & \frac{1}{E_{2,6}} & \frac{1}{E_{3,6}} & \frac{1}{E_{4,6}} & \frac{1}{E_{5,6}} & 1 & E_{6,7} & E_{6,8} & E_{6,9} \\ \frac{1}{E_{1,7}} & \frac{1}{E_{2,7}} & \frac{1}{E_{3,7}} & \frac{1}{E_{4,7}} & \frac{1}{E_{5,7}} & \frac{1}{E_{6,7}} & 1 & E_{7,8} & E_{7,9} \\ \frac{1}{E_{1,8}} & \frac{1}{E_{2,8}} & \frac{1}{E_{3,8}} & \frac{1}{E_{4,8}} & \frac{1}{E_{5,8}} & \frac{1}{E_{6,8}} & \frac{1}{E_{7,8}} & 1 & E_{8,9} \\ \frac{1}{E_{1,9}} & \frac{1}{E_{2,9}} & \frac{1}{E_{3,9}} & \frac{1}{E_{4,9}} & \frac{1}{E_{5,9}} & \frac{1}{E_{6,9}} & \frac{1}{E_{7,9}} & \frac{1}{E_{8,9}} & 1 \end{bmatrix}$$

Figure III-5: Classical AHP evaluation matrix: $\frac{\boldsymbol{n}\times(\boldsymbol{n}-\mathbf{1})}{\mathbf{2}}$ assessments (framed) have to be performed.

Now we introduce transitive evaluations. Therefore, one criterion has to be chosen optionally as fixed comparison criterion, i.e. $E_{r_{fixed},s_{fixed}}$. We select the first criterion in row one, $E_{1,1}$, as fixed comparison criterion, hence in our case all other criteria in the first row have to be evaluated by comparison with this fixed criterion. For the remaining rows, our transitive evaluation formula calculates the respective evaluation value $E_{r,s}$ by division of $E_{r_{fixed},s}$, i.e. the considered criterion's evaluation value which has been assessed manually in the comparison with the fixed criterion, by $E_{r_{fixed},r}$, i.e. the manually assed evaluation value of the rth criterion with the fixed comparison criterion. For instance, the evaluation value of the criterion in row three in column six, $E_{3,6}$, is calculated as follows given the fixed comparison criterion is $E_{1,1}$: $E_{3,6} = \frac{E_{1,6}}{E_{1,3}}$.

The value of our introduced transitive evaluation formula within the AHP method is substantial: Only $n-1$ manual evaluations have to be performed. All other evaluation values are mathematically determined by our transitive evaluation formula. Thus in our study, only eight instead of 36 manual assessments have to be performed – that is a reduction of obligatory assessments of around 80 percent (Figure III-6).

$$\begin{bmatrix} 1 & E_{1,2} & E_{1,3} & E_{1,4} & E_{1,5} & E_{1,6} & E_{1,7} & E_{1,8} & E_{1,9} \\ \frac{1}{E_{1,2}} & 1 & \frac{E_{1,3}}{E_{1,2}} & \frac{E_{1,4}}{E_{1,2}} & \frac{E_{1,5}}{E_{1,2}} & \frac{E_{1,6}}{E_{1,2}} & \frac{E_{1,7}}{E_{1,2}} & \frac{E_{1,8}}{E_{1,2}} & \frac{E_{1,9}}{E_{1,2}} \\ \frac{1}{E_{1,3}} & \frac{E_{1,2}}{E_{1,3}} & 1 & \frac{E_{1,4}}{E_{1,3}} & \frac{E_{1,5}}{E_{1,3}} & \frac{E_{1,6}}{E_{1,3}} & \frac{E_{1,7}}{E_{1,3}} & \frac{E_{1,8}}{E_{1,3}} & \frac{E_{1,9}}{E_{1,3}} \\ \frac{1}{E_{1,4}} & \frac{E_{1,2}}{E_{1,4}} & \frac{E_{1,3}}{E_{1,4}} & 1 & \frac{E_{1,5}}{E_{1,4}} & \frac{E_{1,6}}{E_{1,4}} & \frac{E_{1,7}}{E_{1,4}} & \frac{E_{1,8}}{E_{1,4}} & \frac{E_{1,9}}{E_{1,4}} \\ \frac{1}{E_{1,5}} & \frac{E_{1,2}}{E_{1,5}} & \frac{E_{1,3}}{E_{1,5}} & \frac{E_{1,4}}{E_{1,5}} & 1 & \frac{E_{1,6}}{E_{1,5}} & \frac{E_{1,7}}{E_{1,5}} & \frac{E_{1,8}}{E_{1,5}} & \frac{E_{1,9}}{E_{1,5}} \\ \frac{1}{E_{1,6}} & \frac{E_{1,2}}{E_{1,6}} & \frac{E_{1,3}}{E_{1,6}} & \frac{E_{1,4}}{E_{1,6}} & \frac{E_{1,5}}{E_{1,6}} & 1 & \frac{E_{1,7}}{E_{1,6}} & \frac{E_{1,8}}{E_{1,6}} & \frac{E_{1,9}}{E_{1,6}} \\ \frac{1}{E_{1,7}} & \frac{E_{1,2}}{E_{1,7}} & \frac{E_{1,3}}{E_{1,7}} & \frac{E_{1,4}}{E_{1,7}} & \frac{E_{1,5}}{E_{1,7}} & \frac{E_{1,6}}{E_{1,7}} & 1 & \frac{E_{1,8}}{E_{1,7}} & \frac{E_{1,9}}{E_{1,7}} \\ \frac{1}{E_{1,8}} & \frac{E_{1,2}}{E_{1,8}} & \frac{E_{1,3}}{E_{1,8}} & \frac{E_{1,4}}{E_{1,8}} & \frac{E_{1,5}}{E_{1,8}} & \frac{E_{1,6}}{E_{1,8}} & \frac{E_{1,7}}{E_{1,8}} & 1 & \frac{E_{1,9}}{E_{1,8}} \\ \frac{1}{E_{1,9}} & \frac{E_{1,2}}{E_{1,9}} & \frac{E_{1,3}}{E_{1,9}} & \frac{E_{1,4}}{E_{1,9}} & \frac{E_{1,5}}{E_{1,9}} & \frac{E_{1,6}}{E_{1,9}} & \frac{E_{1,7}}{E_{1,9}} & \frac{E_{1,8}}{E_{1,9}} & 1 \end{bmatrix}$$

Figure III-6: New introduced transitive AHP evaluation matrix: $\boldsymbol{n-1}$ assessments (framed) have to be performed.

Finally in the fourth AHP phase, the final sustainability criteria weights are determined by the eigenvector of the normalized evaluation values matrix (Scott et al., 2013). We define the sustainability criteria weights as weighted evaluation values WE_i (Table III-1).

3.1.4. Improvement of AHP Consistency Ratio

In phase five, a consistency check based on the consistency ratio (CR) is performed to verify whether the judgments are reliable. Based on the well-known formula $CI = \frac{\lambda_{\max} - n}{n-1}$, the consistency index (CI) must be calculated first (Ho et al., 2011). To assess further on whether the made pairwise comparisons are consistent, the consistency ratio (CR) must be computed based on the formulation $CR = \frac{CI}{RI(n)}$ (Alonso and Lamata, 2006). Since we have a matrix with $\mathrm{n} = 9$ sub-criteria, the given random consistency index (RI) is 1.45 (Appendix-Chapter III 1). For consistency quality, a valid CR has been defined as approximately 10 percent or less – otherwise the subjective evaluation must be revised (Saaty, 1990).

By development of our transitive evaluation formula, evaluation inconsistencies – which often occur when applying the classical AHP method in practice (Greco et al., 2013; Ishizaka, 2014) – are impeded: The pairwise comparisons take place against one fixed criterion only. All remaining evaluation values are mathematically calculated preventing inconsistencies. Hence, the CR is always 0 percent implying there are no inconsistencies.

3.2. Development of the Integrated AHP-TSO Method for Measuring and Comparing Suppliers' Weighted Sustainability Performances

3.2.1. Overview of the Integrated AHP-TSO Method

The second problem we consider in this paper is the one of sustainability performance measures and non-comparable metrics.

Based on the TCO notion, we introduce our TSO approach which takes into account all sustainability costs, i.e. economic, social, and environmental costs, evoked by the selection of a certain supplier. Our TSO method measures suppliers' sustainability performances and achieves a supplier ranking for final selection in combination with the previously determined sustainability criteria weights by use of our novel AHP method.

We propose a five-step approach for determining suppliers' weighted sustainability performances:

1. Step: The determination of the measurement metrics for each criterion.
2. Step: The measurement of suppliers' performances on the sustainability criteria.
3. Step: The calculation of the scaled inverse sustainability performances for comparability.
4. Step: The multiplication of weighted criteria vectors by suppliers' performance matrix (integrated AHP-TSO method).
5. Step: The construction of the supplier ranking as a result.

Each step is presented next according to our model, tested in our case study.

3.2.2. Introduction of Sustainability Metrics and Measurements

The first step of our sustainability performance approach is to determine the metrics for each selection criterion. On the one hand, we derive sustainability performance measures such as waste in tons from literature (Székely and Knirsch, 2005). On the other hand, we introduce novel measurements for the quantification of the sustainability criteria: We use binary measurement categories such as yes-no answer options for the social sub-criteria of "Code of Conduct" and offer ordinal scales such as a risk assessment on a 1-to-10-

scale for the social sub-criteria of "Compliance". As a result, we present the criteria measurements shown in Table III-2.

Table III-2: Definition of sustainability performance measures.

Sustainability Dimension	Sub-Criteria	Measures/Units
Environmental	Emissions	CO_2-equivalent in gram per unit
	Energy	Energy in kilowatt-hour per unit
	Waste	Weight in tons per unit
Economic	Price	Initial price in Euro per unit
	Quality	Deficit goods in parts per million
	Time	Error rate reliability in percent of deliveries
Social	Security	Number of work accidents per year
	Code of Conduct	Implementation of CoC on binary scale (yes=1/no=2)
	Compliance	Risk assessment on scale of 1-to-10 (1= no risk; 10 = high risk)

All units are constructed in line with the TSO notion that the higher the measurement is, the worse the performance. For example, the higher the figures of criteria such as price, emissions and work accidents, the worse the supplier's sustainability performance is considered. Therefore, a low measurement is desirable.

The second step of our model comprises the assessment of suppliers' sustainability performances SP based on these measures. Therefore, each supplier is evaluated on each respective sustainability criterion. The resulting supplier performance measures per criterion, however, are determined by use of different metrics and thus are difficult to compare for the purpose of selecting the most sustainable supplier (see our case study measures in Appendix-Chapter III 2).

3.2.3. Development of Scaled Inverse Sustainability Performances

Hence, in the third step, we introduce the calculation of the scaled inverse sustainability performance $SISP$.

Developed mathematical formulation for the $SISP$:

$$SISP_{k,i} = \frac{\frac{1}{m}\sum_{j=1}^{m} SP_{j,i}}{SP_{k,i}}$$

Table III-3: Definition of the elements sustainability performance, scaled inverse sustainability performance and weighted scaled inverse sustainability performance.

Element	Indices	Explanation
$SP_{k,i}$	$k = 1 \dots m$ $i = 1 \dots n$	Sustainability performance of supplier k determined for the criterion C_i; m = number of suppliers; n = number of criteria
$SISP_{k,i}$	$k = 1 \dots m$ $i = 1 \dots n$	Scaled inverse sustainability performance of supplier k determined for the criterion C_i;
$WSISP_{d,k}$	$d = 1 \dots N$ $k = 1 \dots m$	Weighted scaled inverse sustainability performance of supplier k determined by decision maker d; N = number of decision makers e.g. departments

To determine the $SISP$ of supplier k, the arithmetic mean of m suppliers' SP measurements determined for the criterion C_i has to be divided by the SP of supplier k determined for criterion C_i. Thereby, all metrics are eliminated and thus suppliers'$SISP$s determined for all n criteria can be contrasted with each other. Additionally, the performance order is inverted so that the highest $SISP$ value is the best. An illustration for the $SISP$ is shown based on our case study in the Appendix (Appendix-Chapter III 3).

3.2.4. Introduction of the Integrated AHP-TSO Method: Determination of Weighted Scaled Inverse Sustainability Performances

In the fourth step, the advanced AHP method is integrated into the TSO method in order to achieve the supplier selection per department: The subjective sustainability criteria weights, WE_i, per decision maker (derived by the advanced AHP method as presented in section 3.1.) are consolidated on department level and multiplied by the objective suppliers' scaled inverse sustainability performances, $SISP_{k,i}$ (calculated in the previous TSO step). Therefore, the overall criteria weights per department have to be determined. We assume each decision maker per department has the same decision authority. Thus, we calculate for each criterion the arithmetic mean of the weights of the involved decision makers and present the resulting department criteria weights as vector W_dE_i. Each of these departments' criteria vectors W_dE_i is multiplied by the scaled inverse sustainability performances, $SISP_{k,i}$, of the suppliers to be selected written as matrix.

Integrated AHP-TSO method – mathematical formulation for the $WSISP$ of department d:

$$WSISP_d = [WE_1 \quad WE_2 \quad WE_3 \quad \dots \quad WE_n] \times \begin{bmatrix} SISP_{1,1} & SISP_{2,1} & SISP_{3,1} & & SISP_{m,1} \\ SISP_{1,2} & SISP_{2,2} & SISP_{3,2} & & SISP_{m,2} \\ SISP_{1,3} & SISP_{2,3} & SISP_{2,3} & \dots & SISP_{m,3} \\ & & \dots & & \\ SISP_{1,n} & SISP_{2,n} & SISP_{3,n} & & SISP_{m,n} \end{bmatrix}$$

For instance, the criteria weights evaluated by the procurement department and written as vector are multiplied with the suppliers' scaled inverse sustainability performances presented as a matrix (Appendix-Chapter III 4).

The result of these calculations is a vector per department consisting of the weighted $SISP$ – defined as $WSISP_d$, the weighted scaled inverse sustainability performances – of the available suppliers.

$$WSISP_d = \left[\sum_{i=1}^{n} WE_i \, SISP_{1,i} \quad \dots \quad \sum_{i=1}^{n} WE_i \, SISP_{m,i}\right]$$

Hence, each department constructs with the $WSISP_d$ a supplier ranking based on its subjective preferences by criteria weights in combination with the suppliers' objective sustainability performances.

3.2.5. Final Supplier Ranking and Selection

In the fifth step, the final supplier selection occurs. Therefore, a corporate supplier ranking is drawn, depending on each departments' decisional authority. Like on department level, we assume on company level that all involved departments have the same authority to decide the final supplier selection. Consequently, for each supplier k the sum of the $WSISP$s per department is calculated (Appendix-Chapter III 5).

Finally, the supplier with the largest $WSISP$ over all departments is selected:

$$\max_{k=1,\dots,m} \sum_{d=1}^{N} WISP_{d,k}$$

In summary, we have derived a sustainable supplier ranking. Therefore, we have constructed sustainability criteria measurements and converted them to be consistently evaluated. Lastly, we have combined these objective sustainability measurements of the suppliers to be selected with the subjective criteria weights of the departments involved in the supplier selection.

4. Model Evaluation by Scenario-Based Pre-Test and Multiple Case Study

In the previous section, we have mathematically developed a quantitative supplier selection model that links sustainability criteria that are weighted differently by various departments with scaled inverse measurements of suppliers' sustainability performances. In this section, we empirically demonstrate the effectiveness of our model by conducting a scenario-based pre-test in the laboratory followed by a multiple case study in the field. Our case study model, which specifies our conceptual model (Figure III-1), is depicted in Figure III-7.

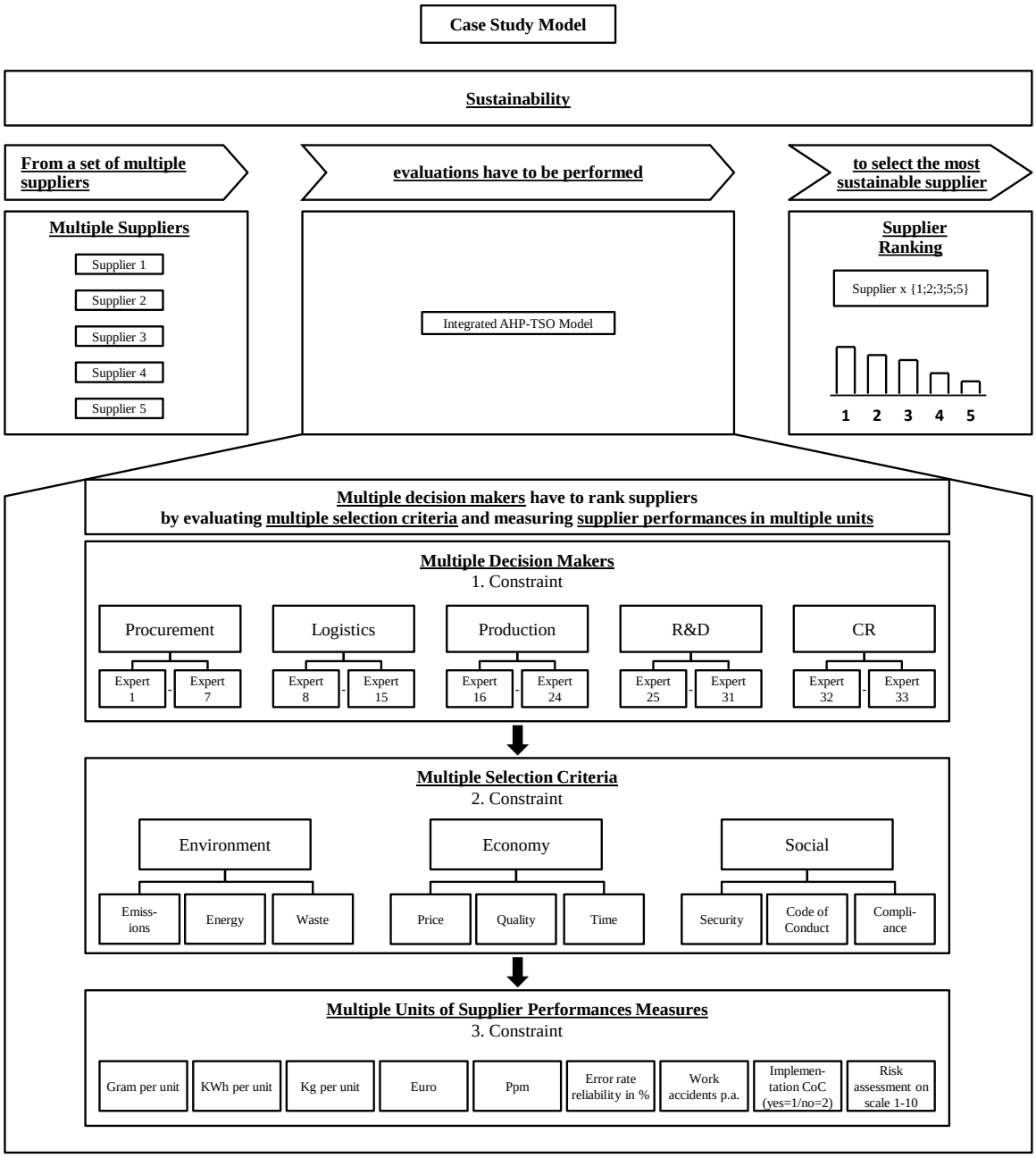

Figure III-7: Case study model: Determination of decision makers (departments), selection criteria (sustainability criteria) and their units (sustainability measures).

4.1. Scenario-Based Pre-Test

A scenario-based pre-test with experts represents the first part of our multi-method research study, as suggested by Bono and McNamara (2011). Thereby, the maturity of our model is ensured, and, similarly, the data validity of our case study is guaranteed.

In our scenario-based pre-test, 15 sourcing and sustainability experts were randomly grouped into four departments that are relevant in sourcing decisions. In doing so, three participants were assigned to the procurement department, four to the logistics department, five to the production department and three to the R&D department. The following sourcing scenario was presented: A high-tech company in the automotive industry in Germany wanted to select a new supplier for seat covers. Additionally, a short description of each department's perspective was sketched. The experts were asked to evaluate nine sustainable sourcing criteria (those derived from literature as presented in section 3.1.1.) by pair-wise comparison under the special consideration of each functional perspective.

4.2. Multiple Case Study

In our multiple case study, we chose to focus on the high-tech industry for two reasons: First, this industry is one of the fastest growing industries with enormous relevance for the world economy (Yan et al., 2016). Second, the commitment to sustainability within this sector is crucial due to global environmental and social standards as well as competitive pressures for sustainable efficiencies of the whole supply chain (ibid.). The three selected high-tech companies *Alpha*, *Beta* and *Gamma* are multinational firms in the automotive and ICT sector with headquarters in Europe (Table III-4).

All firms were addressed through previously established contacts to company management and asked to apply our integrated AHP-TSO model in with established sourcing teams. They involved 18 employees from different departments such as procurement, logistics, production, research & development and corporate responsibility in our study. Absolute anonymity and the responsible treatment of the data for scientific purposes only were assured in advance.

Table III-4: Presentation of the multiple case study.

Case details	*1. Alpha*	*2. Beta*	*3. Gamma*
Revenue [in million €]*	70,000	60,000	10,000
Employees*	200,000	80,000	60,000
High-tech industry, sector	Information and communications technology	Automotive	Automotive
Departments	Procurement, Logistics, Production, R&D, CR	Procurement, Logistics, Production, R&D	Procurement, Logistics, Production, R&D
Number of participants	10	4	4

* in 2016

5. Results

5.1. Results of the Criteria Weightings

5.1.1. Results of the Criteria Weightings on Company Level

All three cases – *Alpha*, *Beta*, and *Gamma* – rank the economic criteria highest, with an average of 44%, followed at a certain distance by social and environmental criteria, with the same average weights of 28% (Table III-5). Hence, the first finding is that no equal distribution with relevance levels of one-third each occurs. Therefore, our model passed its evaluation in a first instance: In a market economy, the economic dimension was evaluated as the most relevant, as expectable, therefore proving the validity of our model.

Table III-5: Overview of the results of the sustainability weights.

	Alpha	*Beta*	*Gamma*	**Average**
Environmental	26%	31%	27%	**28%**
Economic	49%	42%	41%	**44%**
Social	25%	27%	32%	**28%**

Next, we take a closer look at the weightings of the nine criteria themselves. As identified previously, all three cases consider the economic dimension to be the most relevant. Interestingly, quality, not price, is the criterion that has been evaluated as the most important: Every case sets quality in the first place, with an average weight of 18%. The criteria that rank two to five share close proximity: Waste, price, security, and time all have rounded weights of 13%. Similarly, places six to eight are near each other: Energy (10%), code of conduct (8%), and compliance (7%). The least importantly ranked criterion – two out of three cases rank it at a distant ninth place – is emissions, with an average weight of 5% (Table III-6 and Appendix-Chapter III 6).

Table III-6: Results of the criteria weights (three cases, 18 participants).

	Alpha		***Beta***		***Gamma***		**Overall**	
	Weights	Ranks	Weights	Ranks	Weights	Ranks	**Weights**	**Ranks**
Emissions	9%	5	3%	9	2%	9	**5%**	**9**
Energy	9%	6	9%	5	11%	5	**10%**	6
Waste	8%	7	18%	2	14%	3	**13%**	**2**
Price	17%	2	8%	6	14%	2	**13%**	**3**
Quality	20%	1	19%	1	16%	1	**18%**	**1**
Time	12%	4	15%	3	11%	6	**13%**	5
Security	13%	3	13%	4	13%	4	**13%**	4
CoC	7%	8	7%	7	10%	7	**8%**	7
Compliance	6%	9	7%	8	9%	8	**7%**	8

5.1.2. Results of the Criteria Weightings on Department Level

In analyzing the criteria weightings of the different departments, i.e. procurement, logistics, production, research and development (R&D), and corporate responsibility (CR), again the validity of our model can be approved: Apart from CR, the departments

rate the economic dimension as the most important. CR, by nature, weighs the social and environmental dimensions as much more important than the economic dimension.

Moreover, the criteria evaluated as the most relevant best represent the diverse functional perspectives: The procurement function weighs price, logistics function time, production function security, R&D function quality and CR function emissions as the most relevant criteria (Appendix-Chapter III 7). These findings are another support of validity when evaluating our model: The subjective appraisals of the respective departments are validly transferred to objective, quantitative weightings that appropriately represent each functional perspective and offer the possibility of comparison.

5.2. Results of the Final Supplier Selection

We now show the outcome of the suppliers' sustainability measurements. The results of the suppliers' weighted scaled inverse sustainability performances, $WSISP$, as evaluated by the departments of the cases are presented next (Appendix-Chapter III 8).

The final weighted supplier rankings show a preference for Supplier 2 (aggregated $WSISP$ of 23), closely followed by Supplier 4 (aggregated $WSISP$ of 22). Similarly, in all three cases, Supplier 1, Supplier 3 and Supplier 5 are ranked near each other at a certain distance from the first two suppliers. Supplier 5 is ranked in last place in all cases, whereas the order of Supplier 1 and Supplier 3 varies: *Alpha* and *Gamma* rank Supplier 3 in third place and Supplier 1 in fourth place, whereas *Beta* inverts the order of these two suppliers (Table III-7, Figure III-8).

Table III-7: Final supplier rankings by *Alpha*, *Beta*, *Gamma* (figures).

	Alpha		***Beta***		***Gamma***		**Final Supplier Ranking**	
	WSISP	Ranks	*WSISP*	Ranks	*WSISP*	Ranks	Aggregated *WSISP*	Ranks
Supplier 1	5.3	**4**	4.4	**3**	4.3	**4**	14	4
Supplier 2	8.7	1	7.3	1	7.0	1	**23**	**1**
Supplier 3	5.7	**3**	4.4	**4**	4.4	**3**	14	3
Supplier 4	8.5	2	6.7	2	6.4	2	**22**	**2**
Supplier 5	4.6	5	3.6	5	3.7	5	12	5

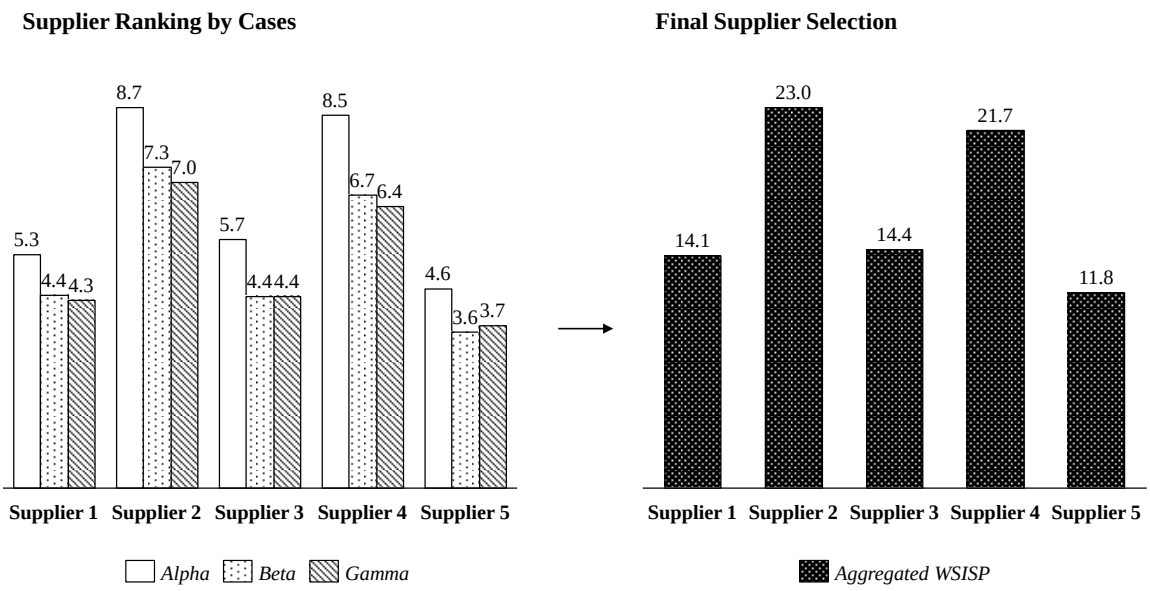

Figure III-8: Final supplier rankings by *Alpha*, *Beta*, *Gamma* and the final supplier selection (graph).

5.3. Sensitivity Analysis: Impact of Criteria Weights and Supplier Performances on the Final Selection in the Integrated AHP-TSO Method

We perform sensitivity analyses to investigate the impact of the criteria weights determined by subjective evaluations and suppliers' sustainability performances assessed by objective measurements as Govindan et al. (2015) suggest. Thereby, it can be observed that Suppliers 2, 4, and 5 are ranked the same independent from the application of criteria

weights (Table III-8). The impact of the criteria weights determined by the departments' evaluations, however, can be stated at several points. First, the ranking of Supplier 1 changes from third place to fourth place and thus is downgraded by the criteria evaluations. By contrast, Supplier 3 is upgraded, rising from fourth place to third place. Second, although the rank of Supplier 4 does not alter, its position improves the most in terms of percentage points when incorporating the departments' weightings. Then, it is only two percentage points beyond Supplier 1 and thus would almost be finally selected as most sustainable supplier based on its aggregated $WSISP$ (Table III-8).

Moreover, the impact of the criteria weights is obvious if the three sustainability criteria dimensions are set as dominant dimension each. Therefore, the respective dominant sustainability dimension has an assigned weight of 100 percent, whereas the other two dimensions have assigned weights of 0 percent. As a result, a dominant environmental dimension would lead to a selection of supplier 1 that is ranked on third place only by its sustainability performance, a dominant economic dimension would lead to a selection of supplier 4 ranked on second place by its sustainability performance, and a dominant social dimension would select supplier 2 that is also ranked highest by its sustainability performance. This broad variety stresses the impact of the subjective weights: The subjective assessments can have a significant impact on the final selection of a certain supplier.

Table III-8: Sensitivity analysis by comparison of suppliers' scaled inverse sustainability performances – unweighted and weighted.

	Unweighted Performances ($SISP$)			**Weighted Performances ($WSISP$)**		
	Absolute	Percentage	Rank	Absolute	Percentage	Rank
Supplier 1	10	18%	**3**	14	17%	**4**
Supplier 2	15	26%	1	23	27%	1
Supplier 3	10	17%	**4**	14	17%	**3**
Supplier 4	13	23%	2	22	25%	2
Supplier 5	9	15%	5	12	14%	5

In summary, in our analyzed scenario, the supplier's immanent sustainability performances exert a large influence. On the other hand, it has also been shown that the departments' criteria evaluations have a substantial impact on the final supplier ranking. Hence, both linked measurements are required to determine the best sustainable supplier from a firm's overall perspective as suggested in our integrated AHP-TSO method.

6. Conclusion and Implications

6.1. Academic and Managerial Contributions

In this paper, we have developed a practical model for sustainable supplier selection by introducing a novel, integrated AHP-TSO method. Thereby, we have considered all three dimensions of sustainability holistically, i.e. the economic, environmental, and social dimension. Accordingly, the most sustainable supplier from a firm's overall perspective is determined quantitatively by means of a ranking integrating both subjective and objective evaluations assessed by our novel AHP-TSO method. Finally, we have found support for the practical use of our model by empirically testing it in a pre-test with experts followed by a multiple case study in the high-tech sector.

In detail, first we have developed a conceptual model that depicts the three problems of sustainable supplier selection we focused on: Multiple departments with opposing preferences have to select the most sustainable supplier by evaluation of multiple conflicting sustainability criteria and assessment of suppliers' sustainability performances by use of multiple non-comparable metrics (Figure III-1).

Second, we have introduced a novel, simpler quantitative model for sustainable supplier selection for practical use in the industry. Our integrated AHP-TSO method consists of a

two-level approach (Figure III-2): Initially, sustainability criteria weights are assessed by multiple departments through application of our developed AHP method. Then, the supplier's scaled inverse sustainability performances are determined following our TSO notion. Last, both measurements are combined. Through this integrated two-level approach, both subjective evaluations and objective performance measurements are respected in the final supplier selection.

The integrated AHP-TSO method embraces the following contributions for both academic research and managerial practice:

For the criteria evaluations to be done in the AHP method, we have established a more intuitive scale from -9 to +9 linked with a shift of the equal relevance point to the more logical center of zero. We tested the scale in our multiple case study and presented it in the design of a slider to the participants (Figure III-4). As a result, a significant time reduction in explaining and understanding our new intuitive scale could be reached when comparing our pre-test without the new scale to the case study with the new scale.

In addition, we have developed the AHP method by our mathematical formula for transitive evaluations. Thereby, we achieved to minimize the number of obligatory assessments and to reduce the complexity of the AHP method essentially. While in the classical AHP method $\frac{n\times(n-1)}{2}$ assessments had to be performed by each decision maker, in our transitive AHP method only $n-1$ assessments have to be done. Hence, in our case study with nine criteria, eight assessments had to take place compared to 36 assessments necessary before, i.e. a reduction of obligatory assessments of 80 percent.

Moreover, our transitive evaluation formula erases inconsistencies defined in literature by a CR of more than 10 percent. Beside the noted $n - 1$ assessments, in our model all evaluation values are calculated mathematically inhibiting potential inconsistencies. Consequently, no criteria evaluation values are inconsistent; our CR is always at its optimum of 0 percent.

In a nutshell, our transitive AHP method minimizes its inherent complexity and maximizes the quality of the evaluation results. Thereby, it may help to overcome the lack of a wider spread of existing models for sustainable supplier selection in business practice.

Furthermore, we have developed a method to measure and contrast the suppliers' sustainability performances. Therefore, we have first introduced measurement units for sustainability criteria. Then, to overcome the issue of comparing different metrics, we have presented a mathematical formulation to eliminate all units and inverted the order of the performance measures. As a result, the higher the scaled inverse sustainability performance $SISP$ of a supplier, the more preferable it is in the final selection.

With respect to business practice, our developed AHP-TSO method reduces complexity on the one hand and enhances consistency on the other hand. Hence, with significant less effort in time and personnel resources, our model is easy to apply in the industry as part of supplier selection decisions. Using it, different decision makers in different departments can consolidate their experiences and knowledge. Moreover, decisional transparency is given for realization support. Finally, the alignment of different

departmental strategies is achieved, favoring the firm's corporate strategy and, consequently, its business success.

6.2. Limitations and Avenues for Further Research

Two limitations of our study offer avenues for further research:

First, we have used illustrative supplier performances in our case studies. When performing our sensitivity analyses, it seemed like the measurements of suppliers' sustainability performances might have a greater impact on the final supplier selection than departments' criteria weightings. Hence, in future studies, real supplier performance measurements should be employed to further investigate this matter.

Second, we have conducted our multiple case study in the high-tech industry with companies in the ICT and automotive sector. Thus, future studies should extend the scope and test our model in different industry settings where opposing decision makers have to make a common decision based on criteria that are difficult to measure to achieve the best overall solution.

IV. A Quantitative Sustainable Sourcing Model for Supplier Selection and Order Allocation*

Abstract

The historical agreement on climate change in Paris in 2015 has recalled the global attention for the pivotal subject of sustainability. Sustainable sourcing, i.e. integrating environmental, social, and economic issues into sourcing decisions, has been studied as a relevant part of sustainability in academic and managerial research papers. However, the focus has been set on conceptual models: Only ten percent of sustainable sourcing models are quantitative. To fill this lacuna in research, in this research paper we have developed a quantitative sustainable sourcing model to select suppliers and determine order quantities. In detail, we have considered a multiple supplier problem with capacity constraints, fixed charges and salvage values. Based on the newsvendor model, we have – for the first time to our knowledge – considered the end product demand and price as functions of the suppliers' sustainability level.

Having empirically tested our model by sensitivity analyses and 42 representative examples, we have three findings: First, our model has determined that, despite increasing demand uncertainty, the benefit of higher order quantities does not always compensate the reduction of the end product price when switching to another, less sustainable pool with higher capacities. Second, the benefit of higher stocks does not consistently outweigh the additional fixed charges if supplementary other suppliers in the same pool were procured from. Third, the coefficient of variation of demand has to be considered within supplier selections to avoid negative profits.

Future research may enhance our single to a multi-period model and explore more deeply the correlation of parameter changes and profit under sustainability constraints.

Keywords: *Sustainable sourcing; quantitative model; supplier selection; order allocation; newsvendor model.*

* This essay is co-authored by Matthew Keblis.
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1. Introduction – Need for quantitative sustainable sourcing models

The historic climate change agreement in Paris in 2015 has attracted the worlds' attention for the pivotal subject of sustainability: The balanced use of environmental, social, and economic resources defined as sustainability (Elkington, 1998; Kleindorfer et al., 2005) is more relevant than ever to reach the ambitious target of limiting global warming to two degree Celsius. Managers have to consider the three aspects of sustainability in their sourcing decisions with regard to supplier selection and order allocation: Not the supplier with the lowest costs, but the supplier that enables the most sustainable business has to be chosen to ensure steady profits in the long-term.

Just as in sourcing decisions, the same shift from cost focus to sustainability focus has taken place in customers' purchase decisions: Around 70 percent of global customers are "willing to pay more for sustainable goods" (Nielsen Global Survey, 2015). Furthermore, even nine out of ten global citizens say they would boycott companies exhibiting the impression of acting irresponsibly (Cone Communications, 2015). Such evidence strongly pushes firms to holistically embrace all three aspects of sustainability, i.e. environmental, social, and economic aspects in their sourcing and pricing decisions.

However, the occurrence of events such as the present emissions scandal of Volkswagen (VW) reveals that social and environmental concerns have not been considered as relevant as quick wins by all companies. Thus, to reach the legally binding climate targets of Paris, it is necessary to include all sustainability aspects also in firms' supplier selection decisions with the help of models and tools. Nevertheless, a review paper by Tang and Zhou (2012) suggests a shortage of quantitative models for making sustainable sourcing decisions. They observe that "there are very few (almost none) quantitative procurement/sourcing models that deal with environmental/social responsibility issues."

This lack of quantitative sustainable sourcing models has been confirmed by a recent review of more than 1,000 publications by Fahimnia et al. (2015): Only ten percent use quantitative models. Hence, we fill the identified lacuna in the world of sustainable supply chain management (SSCM) with our research by developing a quantitative supplier selection and order allocation model for sustainable sourcing.

We aim at incorporating three aspects in our model: First, we develop a mathematical sustainable sourcing model that a manufacturer of a short life cycle can use to select the suppliers to source a component from and to determine the quantity to procure from each supplier. Second, we suppose sustainability impacts demand positively: Paralleling the idea that a greener product generates higher demand (Nouira et al., 2014; Raz et al., 2013), we posit that the use of more sustainable suppliers enables the manufacturer to increase the demand for its end product. Third, we simultaneously assume that sustainability affects the price in such a way that the selection of more sustainable suppliers allows the manufacturer to request a higher price for its end product. By integrating these premises into our model, we show how a sustainable sourcing decision impacts both revenue management and cost containment to maximize final profits.

The remainder of this paper is organized as follows: In the next section, we review relevant literature on sourcing models incorporating sustainability and mathematical approaches. In the subsequent section, we describe our problem setting of interest and present our mathematical problem formulation as a mixed integer programming model. In the penultimate section we run sensitivity analyses to determine the impact of our variables, exercise our mathematical programming model for 42 representative examples and discuss our findings. We end the paper with a summary of our work, point out implications and delineate avenues for future research.

2. Literature Review – Sustainable sourcing models lack quantitative approaches

The research we present in this paper is related to two streams of research: research on sourcing models incorporating sustainability and mathematical sourcing models with a focus on the newsvendor model. In the subsequent sections, we provide a brief review of both streams and identify the research gap that motivates our research.

2.1. Sourcing Models Incorporating Sustainability

As part of SSCM, sustainable sourcing integrates sourcing decisions with explicit consideration of environmental and social aspects in addition to traditional economic aspects (Singhry, 2015). Thereby, supplier selection and order quantities are determined under consideration of sustainability aspects (Azadnia et al., 2015). In doing so, a positive effect on a firm's financial performance and competitive advantage can be shown (Ağan et al., 2016; Singhry, 2015).

Many research papers have investigated the subject of sustainability along the supply chain (Brandenburg et al., 2014; Fahimnia et al., 2015; Sarkis and Dhavale, 2015). However, mostly conceptual models have been employed: Only about 10 percent of SSCM papers integrate quantitative models into their research (Brandenburg et al., 2014; Fahimnia et al., 2015). This lack of quantitative sourcing models that incorporate sustainability issues can be confirmed by recent literature reviews (Ashby et al., 2012; Hassini et al., 2012; Miemczyk et al., 2012; Seuring, 2013; Tang and Zhou, 2012; Taticchi et al., 2015).

Hitherto, it has been shown that a greener product increases its demand and price (Nouira et al., 2014; Raz et al., 2013). We transfer these findings and assume that the sustainability level of suppliers positively affects both demand and price of the end product.

Motivated by the previously presented lacuna in research, we develop a quantitative sourcing model that uses suppliers' sustainability levels to select the optimal suppliers as well as to determine optimal order quantities in order to maximize a manufacturer's profit.

2.2. Mathematical Sourcing Models with a Focus on the Newsvendor Model

Sourcing can be divided into three phases:

1) Supplier evaluation: establishing a supplier base;
2) Supplier selection: choosing suppliers from the base;
3) Quantity allocation: determining the quantity to procure from each supplier selected (Burke et al., 2007).

In this paper we assume the manufacturer has already established a supplier base. Thus, we focus on the literature of mathematical sourcing models pertaining to the supplier selection and quantity allocation problem.

Mathematical models, such as linear programming, multi-objective programming or data envelopment analysis, have been applied in general supplier selection problems (Kannan et al., 2013; Snyder et al., 2016). As basis for our model we use the linear programming model. In particular, we make use of the so-called newsvendor model, which determines optimal order quantities restricted by uncertain demand and salvage value in a single period model (Dada et al., 2007). As in the problem setting studied by Zhang and Zhang (2011), we set up a newsvendor model with multiple suppliers, finite capacities and fixed

charges facing stochastic demand. Following the studies on price-sensitive demand by Yu et al. (2009), we additionally integrate both sustainability-sensitive demand and price determined by different sustainability levels of the selected suppliers.

2.3. Objective of this Paper – Mathematical model incorporating sustainability

As presented in the previous sections, relevant research has been conducted with respect to sustainable sourcing models on the one hand and mathematical sourcing models on the other hand. However, there are three research issues that have not been studied comprehensively yet, which we want to investigate in this paper:

First, there are almost no quantitative sustainable sourcing models (Fahimnia et al., 2015). Furthermore, the few prior works that adopt the newsvendor model to the field of sustainability do not holistically embrace the issue of sustainability as they only consider green issues and do not take social issues into account (Raz et al., 2013; Rosič and Jammernegg, 2013).

Second, research is missing with regard to sustainability levels determining order allocations (Azadnia et al., 2015). Moreover, sustainability aspects should be considered to develop classical inventory models, i.e. the newsvendor model, to shield against uncertainty (e.g. in demand) and maximize profits (Azadnia et al., 2015; Bushuev et al., 2015).

Third, the impact of price-setting determined by sustainability has not been explored yet in the newsvendor model: Recent papers with a focus on the newsvendor model call for further research on the relation of price and demand by varying main input variables (e.g. sustainability) (Rubio-Herrero et al., 2015; Xu and Lu, 2013).

In summary, we refer to the calls for further research regarding quantitative sustainable sourcing methodologies. Thus, we want to develop a model that investigates a setting with multiple suppliers with different capacity constraints, component prices and fixed charges as well as with diverse sustainability levels that determine end product price and end product's expected demand. In this paper we treat, for the first time to our knowledge, end product demand and end product price as a function of the sustainability of the suppliers used by the manufacturer.

3. Development of a Mathematical Sustainable Sourcing Model

3.1. Problem Setting

In the following section we present the framework and introduce necessary constraints of our model.

We consider a manufacturer of a short life cycle end product implying that the end product has a short selling season. The demand for the end product is stochastic. The main component of the end product has a substantial lead time and must be procured from one or more suppliers in advance of the sales period. Each supplier of the main component is restricted in its capacity. When the manufacturer orders from a supplier a fixed charge may be incurred in addition to a cost per unit. Any unsold main components the manufacturer has left over after the sales period have a salvage value that is supplier-specific depending on the supplier's sustainability degree and which may be negative, i.e. there may be a disposal cost.

The target of the manufacturer is to maximize its profits. Hence, the manufacturer is interested in low purchasing cost on the one hand and in high revenues by high demand and high selling prices on the other hand. Though, the characteristics of the main

component and of its supplier(s) may impact the price of and the demand for its end product. In this paper we examine a sourcing problem where the manufacturer is able to obtain a higher price and generate greater demand for its end product if it has been procured from more sustainable suppliers.

Another main construct in our approach to model this problem is a so-called pool. A pool is a collection of one or more suppliers. We assume that the level of a pool's sustainability is determined by the member of the pool with the lowest level of sustainability. Furthermore, we suppose that sourcing from a pool with a higher measure of sustainability enables the manufacturer to obtain a price for the end product that is always at least as high as the price that can be obtained by sourcing from a pool with a lower level of sustainability. The same logic is applied to demand determination by a pool's sustainability level.

We present a mathematical programming model for sustainable sourcing that a manufacturer in this setting can use to determine the optimal supplier pool and the optimal quantity of the main component to procure from each supplier in the pool for maximum profits. The newsvendor model (as introduced in section 2.2) serves as basic input for our mathematical programming model. Candidate procurement quantities are generated to determine an optimal sourcing plan. In our newsvendor model demand for the end product is stochastic and the short life cycle of the product to be sold is reflected. Aside from serving as an appropriate model to be employed in this instance, another benefit of using a newsvendor model is that its overage parameter can be used to explicitly capture a main component's salvage value. In our setting, a salvage value signals a supplier's commitment to sustainability: The salvage value conveys information about a main component's environmental characteristics, such as material chemistry, disassembly and recyclability, and social characteristics, such as conditions of production referring to

workplace safety and health as well as respect for human and workplace rights. In conclusion, we consider suppliers' diverse sustainability levels by three factors: They are reflected in different salvage values, in different end product prices and in different end product demand.

3.2. Model Variables

In this section, we define parameters and variables for our mathematical model formulation. The fixed model parameters are defined in Table IV-1 as follows:

Table IV-1: Definition of fixed model parameters.

Parameter	Values		Explanation
N	$\in \mathbb{N}$		Number of suppliers; also number of pools
S	$\in \mathbb{N}$	$= \{1, \dots, N\}$	Set of suppliers where 1 denotes the supplier with the highest measure of sustainability, 2 denotes the supplier with the second highest measure of sustainability, etc.
S_k $= \{\alpha_{k1}, \dots, \alpha_{kk}\}$		$k = 1, \dots N$ $\alpha \in \mathbb{N}$	Set consisting of the first k suppliers from the set $\mathcal{S}$ ordered according to main component cost where α_{k1} denotes the index of the supplier in S (among the first k suppliers) with the lowest main component cost, α_{k2} denotes the index of the supplier in S (among the first k suppliers) with the second lowest main component cost, etc. Each such set is referred to as a pool in the sequel.
μ_i	$\in \mathbb{R}_{\geq 0}$	$i = 1, \dots N$	Average demand for the end product if the main component is procured from pool S_i.
σ_i	$\in \mathbb{R}_{\geq 0}$	$i = 1, \dots N$	Standard deviation of demand for the end product if the main component is procured from pool S_i
P_i	$\in \mathbb{N}$	$i = 1, \dots N$	Price the manufacturer is able to obtain for a unit of the end product if the main component is procured from pool S_i in \$.
D	$\in \mathbb{R}_{\geq 0}$		Manufacturer's production cost for common components and direct labor for a unit of the end product in \$.
R_i	$\in \mathbb{R}$	$i = 1, \dots N$	Net revenue obtained by the manufacturer for a unit of the end product if the main component is procured from pool S_i in \$; in particular $R_i = P_i - D$.
C_j	$\in \mathbb{N}$	$j = 1, \dots N$	Per unit cost of the main component if it is procured from supplier j in \$.
V_j	$\in \mathbb{R}$	$j = 1, \dots N$	Salvage value of a unit of the main component if it is procured from supplier j in \$.
F_j	$\in \mathbb{N}_0$	$j = 1, \dots N$	Fixed charge incurred if one or more units of the main component are procured from supplier j in \$.
L_j	$\in \mathbb{N}_0$	$j = 1, \dots N$	Limit on the number of units of the main component that supplier j is able to provide, i.e. capacity of supplier j.
Q_{ij}	$\in \mathbb{N}$	$i = 1, \dots N$ $j = 1, \dots N$	Newsvendor quantity* for supplier j in pool S_i.
I_{ij}	$\in \mathbb{N}$	$i = 1, \dots N$ $j = 1, \dots N$	Expected number of unsold main components if units of the main component are procured from supplier j in pool S_i.
E_{ij}	$\in \mathbb{R}$	$i = 1, \dots N$ $j = 1, \dots N$	Expected reduction in profit due to unsold main components if units of the main component are procured from supplier j in pool S_i in \$.
M	$\in \mathbb{N}$		Scaling factor

* Specified in section 3.3.

The parameters that vary in the optimization process are presented in Table IV-2 next:

Table IV-2: Definition of parameters that vary during the optimization process.

Parameter	Values		Explanation
x_i	$\in \mathbb{N}$	$i = 1, \dots N$	Units of the main component procured from pool S_i
y_{ij}	$\in \mathbb{N}$	$i = 1, \dots N$ $j = 1, \dots N$	Units of the main component procured from supplier j in pool S_i
z_i	$\in \{0, 1\}$	$i = 1, \dots N$	Selection of one pool only: One if the main component is procured from pool S_i, otherwise zero
u_{ij}	$\in \{0, 1\}$	$i = 1, \dots N$ $j = 1, \dots N$	Selection of supplier in a pool: One if the main component is procured from supplier j in pool S_i, otherwise zero
v_{ij}	$\in \{0, 1\}$	$i = 1, \dots N$ $j = 1, \dots N$	Selection of subsequent supplier in a pool: One if the main component is procured from supplier j but not supplier $j + 1$ in pool S_i, otherwise zero

3.3. Mathematical Model Formulation

We formulate our supplier selection and quantity allocation problem as a mixed integer programming model. The model determines the pool of suppliers to choose, the suppliers in the chosen pool to be employed and the number of the main components to procure from each employed supplier to maximize profits.

Mathematical model formulation:

$$\max_{\{x,y,z,u,v\}} \sum_{i=1}^{N} R_i x_i - \sum_{i=1}^{N} \sum_{j=1}^{i} C_{\alpha_{ij}} y_{ij} - \sum_{i=1}^{N} \sum_{j=1}^{i} F_{\alpha_{ij}} u_{ij} - \sum_{i=1}^{N} \sum_{j=1}^{i} E_{ij} v_{ij}$$

The constraints for our mathematical formulation are specified in the subsequent Table IV-3.

Table IV-3: Specification of constraints for our mathematical formulation.

Constraints	Values			No.
$x_i = \sum_{j \in S_i} y_{ij}$	$i = 1, \dots, N$			(1)
$y_{ij} \leq L_{\alpha ij}$	$i = 1, \dots, N$	$j = 1, \dots, i$		(2)
$\sum_{k=1}^{j} y_{ik} - M(1 - u_{ij}) \leq Q_{ij}$	$i = 1, \dots, N$	$j = 1, \dots, i$		(3)
$y_{ij} - Mu_{ij} \leq 0$	$i = 1, \dots, N$	$j = 1, \dots, i$		(4)
$u_{ij} = v_{ij}$	$i = 1, \dots, N$	$j = i$		(5)
$u_{ij} - u_{ij+1} = v_{ij}$	$j = 1, \dots, i$	$j \neq i$		(6)
$y_{ij} + M(1 - u_{ij+1}) \geq L_{\alpha ij}$	$i = 1, \dots, N$	$j = 1, \dots, i$	$j \neq i$	(7)
$x_i \leq Mz_i$	$i = 1, \dots, N$			(8)
$\sum_{i \in S} z_i = 1$				(9)
$x_i \geq 0$	$i = 1, \dots, N$			(10)
$y_{ij} \geq 0$	$i = 1, \dots, N$	$j = 1, \dots, i$		(11)
$z_i = 0 \; or \; 1$	$i = 1, \dots, N$			(12)
$u_{ij} = 0 \; or \; 1$	$i = 1, \dots, N$	$j = 1, \dots, i$		(13)
$v_{ij} = 0 \; or \; 1$	$i = 1, \dots, N$	$j = 1, \dots, i$		(14)

The first term of our mathematical model formulation determines the net revenue that the manufacturer can generate when selling the units procured from the pool selected for a price determined by that pool less the manufacturer's direct production costs. The second term calculates the total variable cost of procuring the main component. The third term measures the total fixed charges incurred when procuring the main component. The fourth term of the objective function captures the reduction in profit due to unsold main components.

The first constraint says that the number of main components procured from pool S_i must equal the total number of main components procured from the suppliers in pool S_i. The second constraint requires that the number of main components procured from supplier j in pool S_i must be less than or equal the capacity limit of supplier j. The third constraint

demands that the number of main components procured from supplier j in pool S_i plus the number of main components procured from suppliers in pool S_i with main component cost lower than supplier j must be less than or equal the optimal number of main components to procure from supplier j in pool S_i, i.e. supplier j 's newsvendor quantity in pool S_i. The fourth constraint activates the third constraint for supplier j in pool S_i when supplier j is procured from. The fifth and sixth constraints together ensure that the cost of unsold main components is captured in the objective function only once in case of procuring from pool S_i. The seventh constraint allows the main component to be procured from supplier j in pool S_i only if the entire capacity of supplier $j-1$ is consumed. The eighth and ninth constraints together ensure that the main components are procured from only one pool. The tenth and eleventh constraints are non-negativity constraints. The twelfth constraint enforces an either or decision with regard to selecting one pool only. Finally, the last two constraints enforce an either or decision from each supplier in each pool with respect to procuring.

For every supplier, the newsvendor quantity must be calculated for each pool the supplier is a member of (implied by the third constraint). Supplier 1 of set S is a member of N pools, hence it has N associated newsvendor quantities. Supplier 2 of set S is a member of $N-1$ pools, hence it has $N-1$ associated newsvendor quantities, etc. In order to determine Q_{ij}, i.e. the newsvendor quantity for supplier j in pool S_i, it involves the calculation of the critical ratio

$$Q_{ij} = \frac{c_u}{c_u + c_o}$$

where c_u is the cost of underage and c_o is the cost of overage (Porteus 2002). For supplier j in pool S_i, $c_u = R_i - C_{\alpha_{ij}}$ and $c_o = C_{\alpha_{ij}} - V_{\alpha_{ij}}$.

The calculation of E_{ij}, the expected reduction in profit due to unsold main components, is detailed next. In the following, the term lead supplier refers to supplier 1 of a pool. First, we consider the case where the manufacturer procures the main components exclusively from the lead supplier. If the supplier's capacity is greater than the supplier's newsvendor quantity, then the latter will be procured from the supplier else the quantity procured will equal the capacity of the supplier. In either case $E_{i1} = I_{i1} \cdot \left(R_i - V_{\alpha_{i1}}\right)$. Second, we reflect the case where it is optimal to procure from supplier 2 of pool S_i in addition to the lead supplier. If supplier 2 is procured from, then the entire capacity of the lead supplier has been exhausted. When supplier 2's capacity plus the capacity of the lead supplier is greater than the newsvendor quantity of supplier 2, then the quantity procured from supplier 2 will equal its newsvendor quantity less the capacity of the lead supplier, otherwise the quantity procured from supplier 2 will equal its capacity. In the former case

$$E_{i2} = min\{I_{i2}, \max\{0, Q_{i2} - L_{\alpha_{i1}}\}\} \cdot \left(R_i - V_{\alpha_{i2}}\right) + (I_{i2} - min\{I_{i2}, \max\{0, Q_{i2} - L_{\alpha_{i1}}\}\}) \cdot \left(R_i - V_{\alpha_{i1}}\right)$$

while in the latter

$$E_{i2} = min\{I_{i2}, L_{\alpha_{i2}}\} \cdot \left(R_i - V_{\alpha_{i2}}\right) + (I_{i2} - min\{I_{i2}, L_{\alpha_{i2}}\}) \cdot \left(R_i - V_{\alpha_{i1}}\right).$$

The assumption that main components procured from the lead supplier will be used before those procured from supplier 2 is implicit in these calculations. A similar assumption is made in all cases where more than one supplier is employed.

4. Testing and Discussing the Model

We empirically test our model in a two-step approach: First, we run sensitivity analyses to investigate the impact of selected variables in certain ranges of values. Second, we

define representative examples to illustrate how the model can be used by a manager in making a supplier selection and quantity allocation decision. Both examinations are implemented and run in MATLAB R2016a. The results will be presented and discussed next.

4.1. Sensitivity Analyses

We conduct sensitivity analyses for diverse ranges of values: to start with, we investigate moderate ranges of ±50 percent. Then we explore the behavior of the model for extreme small values close to zero (up to -99.98 percent of the basis value) and extreme large values (up to +99,900 percent of the basis value). Additionally, we vary the number of suppliers under consideration from one to five. As our model integrates a multitude of variables, we concentrate on three variables in our sensitivity analyses that are component price, salvage value and capacity constraints. We thus expect to reveal relevant characteristics of our model.

The procedure of our sensitivity analyses is depicted schematically in Figure IV-1: First, we define a basis scenario with five suppliers having different component prices, salvage values and capacities (see table “Basis Matrix” in Figure IV-1). We write these values as component price vector, salvage value vector and capacity vector. Subsequently, each of the vector is varied by a linear shift of 10 percent each, i.e. from -50 percent to +50 percent, while the other values are kept fix. The variations are designated scenarios 1 to 11 with scenario 6 as a basis scenario meaning the variation there is 0 percent. Consequently, in total 33 scenarios are presented as the three vectors get shifted eleven times each.

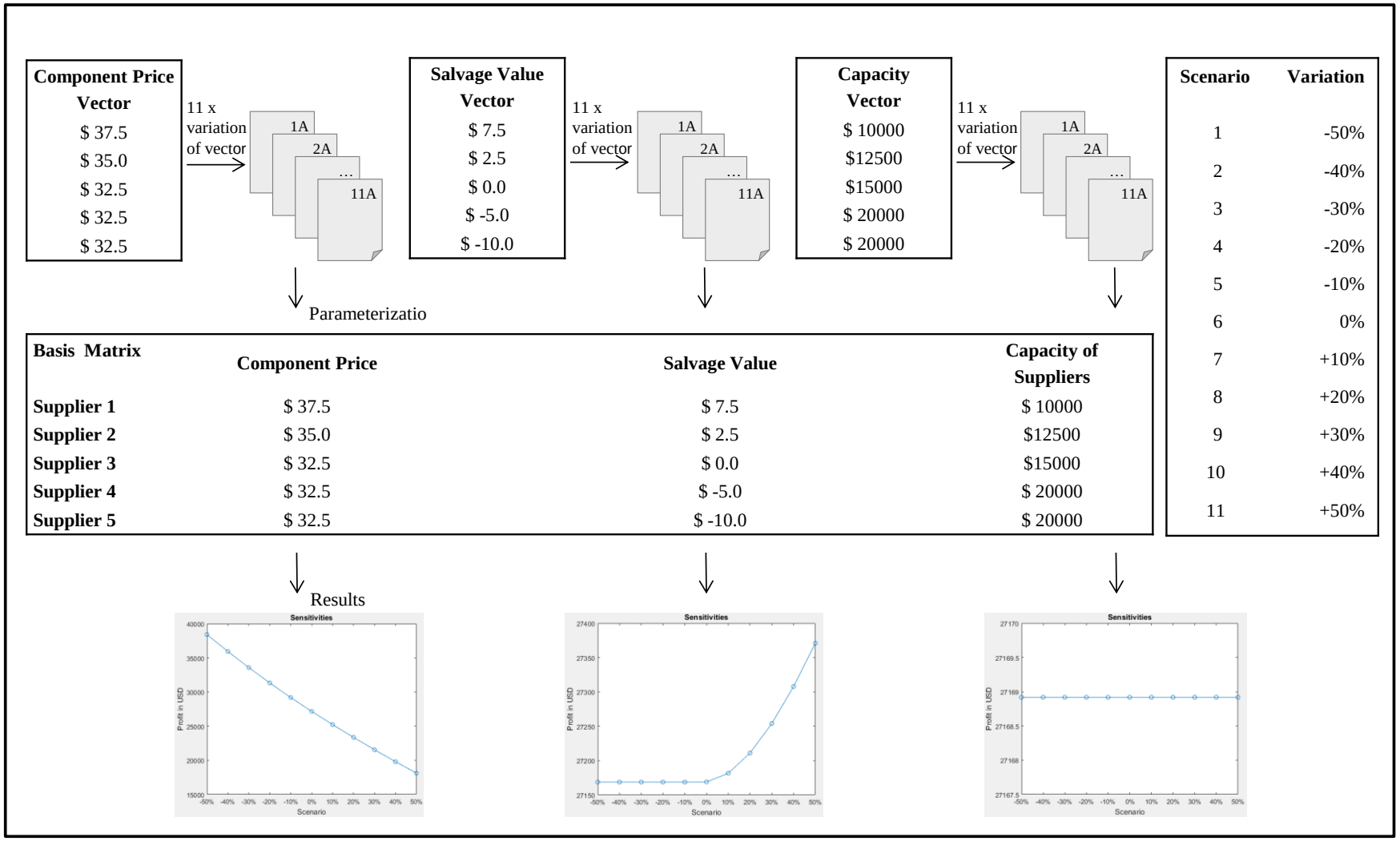


Figure IV-1: Schematic presentation of the sensitivity analyses.

4.1.1. Sensitivity Analysis of Component Price

The results of our sensitivity analyses are depicted in Figure IV-2. When analyzing the first sensitivity analysis with variations of the component price, it can be seen that the price impacts the profit directly in all eleven scenarios as expected: The higher the component price, the smaller the profit. Therefore, the profit curve is decreasing almost linearly if the price increases with shifts of 10 each. Hence, in all scenarios 1-11, the component price has an impact on the final profits.

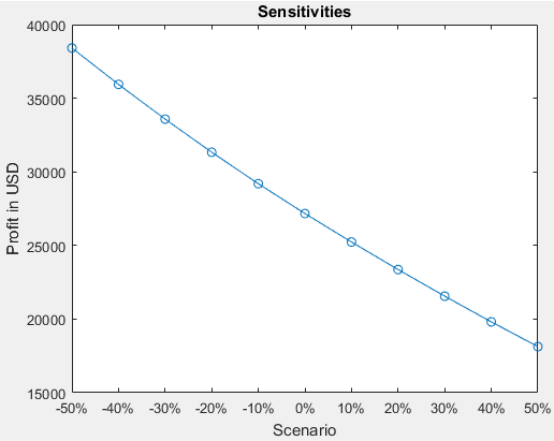
4.1.2. Sensitivity Analysis of Salvage Value

Regarding the results of the second sensitivity analysis with variations of the salvage value that reflects the suppliers' sustainability level (as described in section 3.1.) a contrariwise dependency can be detected: The higher the salvage value, the higher the profit. Interestingly, this relation only holds true for scenarios 7 to 11, where profits almost exhibit an exponential growth even though salvage values rise in linear shifts of 10 percent. Otherwise, the profit is indifferent to the salvage value in scenarios 1-6. Accordingly, it can be stated that in our model the salvage value has to reach a certain value (here: scenario 7 with +10 percent) to have an impact on the final profit. This phenomenon can also be seen in the next section 4.2, where we investigate the results if salvage values are reduced around two third of the original values. Thus, this non-linearity confirms the need for our sustainable sourcing model as a sourcing manager cannot intuitively take different salvage values into account which are relevant for his final decision.

4.1.3. Sensitivity Analysis of Capacity

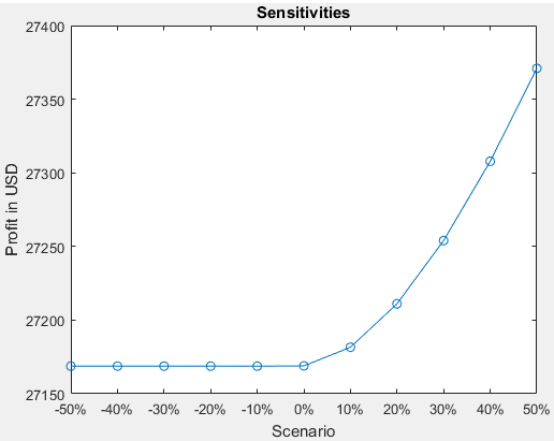
With respect to the third sensitivity analysis with variations of the suppliers' capacities, a similar behavior can be noticed in parts: Even though the capacity increases in linear shifts, the profit curve stays parallel to the x-axis. Accordingly, no impact of the capacity on the profit can be detected within our scenarios of varying the original capacity values in a range of ±50 percent. This demonstrates the significance of our construct of a pool: We assume that the capacity of the lead supplier can be enhanced by the capacity of the other suppliers in the pool. Consequently, the constraint of each supplier's capacity and newsvendor quantity in the context of a pool is crucial when determining optimal order quantities and final profits. We consider this in the next section 4.2 where we focus on the selection of a certain pool and certain suppliers thereof.

Price



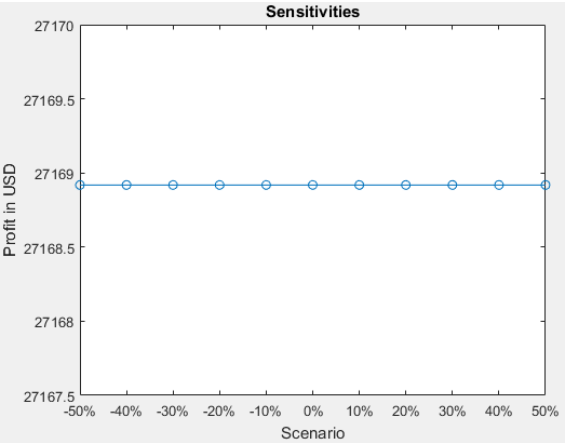
Scenario	Variation	Max Profit
1	-50%	$38,410
2	-40%	$35,940
3	-30%	$33,580
4	-20%	$31,330
5	-10%	$29,190
6	0%	$27,170
7	+10%	$25,230
8	+20%	$23,360
9	+30%	$21,560
10	+40%	$19,810
11	+50%	$18,130

Salvage Value



Scenario	Variation	Max Profit
1	-50%	$27,170
2	-40%	$27,170
3	-30%	$27,170
4	-20%	$27,170
5	-10%	$27,170
6	0%	$27,170
7	+10%	$27,180
8	+20%	$27,210
9	+30%	$27,250
10	+40%	$27,310
11	+50%	$27,370

Capacity



Scenario	Variation	Max Profit
1	-50%	$27,170
2	-40%	$27,170
3	-30%	$27,170
4	-20%	$27,170
5	-10%	$27,170
6	0%	$27,170
7	+10%	$27,170
8	+20%	$27,170
9	+30%	$27,170
10	+40%	$27,170
11	+50%	$27,170

Figure IV-2: Overview of the sensitivity analyses with variations of the component price, salvage value and capacities.

4.2. Representative Examples

In this section, we present the results from 42 representative examples (see Table IV-4 and Table IV-5). The 42 examples are set up as follows: The first 21 examples are all identical except for their demand parameters (μ and σ; in every example we assume demand is log-normally distributed), which also impact the newsvendor quantities $\{Q_{ij}\}$, the expected number of unsold main components $\{I_{ij}\}$, and the expected reduction in profit due to unsold main components $\{E_{ij}\}$. The second set of 21 examples is identical to the first 21 except for a change in salvage values where positive values have been reduced by 65 percent, i.e. by around two third compared to their original values. This means basically all 42 examples are identical except for the parameters μ, σ, Q_{ij}, I_{ij}, E_{ij} and V_{ij}.

To illustrate the examples' settings, we present the details for one example, i.e. Example 5, where we consider a setting with five suppliers ($N = 5$), hence $S = \{1,2,3,4,5\}$. The remaining data for Example 5 is shown in the Appendix (Appendix-Chapter IV 1).

Each of the five suppliers is deemed qualified. In our context, a supplier is qualified if an assessment has determined that the supplier should be able to deliver on time and provide a main component that meets quality standards. Supplier 1 of S is designated as supplier 1 because it is the best supplier from a sustainability perspective. It should be observed that while supplier 1's main component has the highest per unit cost (see vector C), its main component also has the highest salvage value (see vector V), hence supplier 1 can be seen as providing a component with more appealing characteristics in terms of sustainability. At the same time, the capacity of supplier 1 is the most limited of all suppliers (see vector L) and using supplier 1 incurs a fixed charge that is as high as or higher than that of all other suppliers (see vector F). If the manufacturer procures the

main component exclusively from supplier 1, the expected end product price will be highest (see vector P).

Supplier 5 is at the other end of the spectrum which is the worst supplier from sustainability perspective. However, supplier 5's main component has the lowest per unit cost and using supplier 5 incurs no fixed charge although the use of this supplier results in the lowest end product price. Moreover, supplier 5's main component has the lowest salvage value, in fact one that is negative implying that it possesses unappealing characteristics in terms of sustainability so that additional cost incur for example for disposal. Supplier 5 also happens to have the highest capacity of all suppliers. If the manufacturer procures any amount of the main component from supplier 5, the expected end product price will be lowest. The remaining suppliers have profiles that lie between the extremes of suppliers 1 and 5.

4.3 Results and Discussion

4.3.1. General Results – Overview

We give a short overview of the general results of our representative examples (depicted in Figure IV-3 and Figure IV-4), before presenting the results in detail.

As expected, it is valid for all Examples 1-42: The higher the demand, the higher the profit. Likewise it can be observed for all examples: The more units procured, the higher the profit. Concerning the level of uncertainty it can be noted for each triple presented (e.g. triple 19-21), the higher the standard deviation, the lower the profit. With respect to the selection of pools, it is observable that in Examples 1-21, there is a higher diversity when selecting pools, while in Examples 22-42 there is a higher concentration on pool 3. Interestingly in Examples 22-42, pool 1 and 2 are not selected at all. Another difference

between the two sets of examples can be noticed when focusing on the suppliers selected: While in Examples 1-21, there is a clear preference for more sustainable suppliers, in Examples 22-42 with the reduction of the salvage value, however, there is a shift to less sustainable suppliers. Regarding the highest profit per supplier in average, noteworthy in Examples 1-21, the least sustainable suppliers (supplier 4 and 5) have an average profit above overall average profit – and though are selected fewest. In Examples 22-42, the most (supplier 1) and the least sustainable suppliers (supplier 4 and 5) generate average profits above overall average profit – and yet again are chosen fewest.

The overview of the general results stresses the complexity of the sustainable sourcing problem. Neither the most sustainable pool nor the pool with the highest profit on average are always selected. This emphasizes the need for our mathematical sustainable sourcing model to determine the optimal solution in terms of supplier respectively pool selection, order quantities and profit maximization.

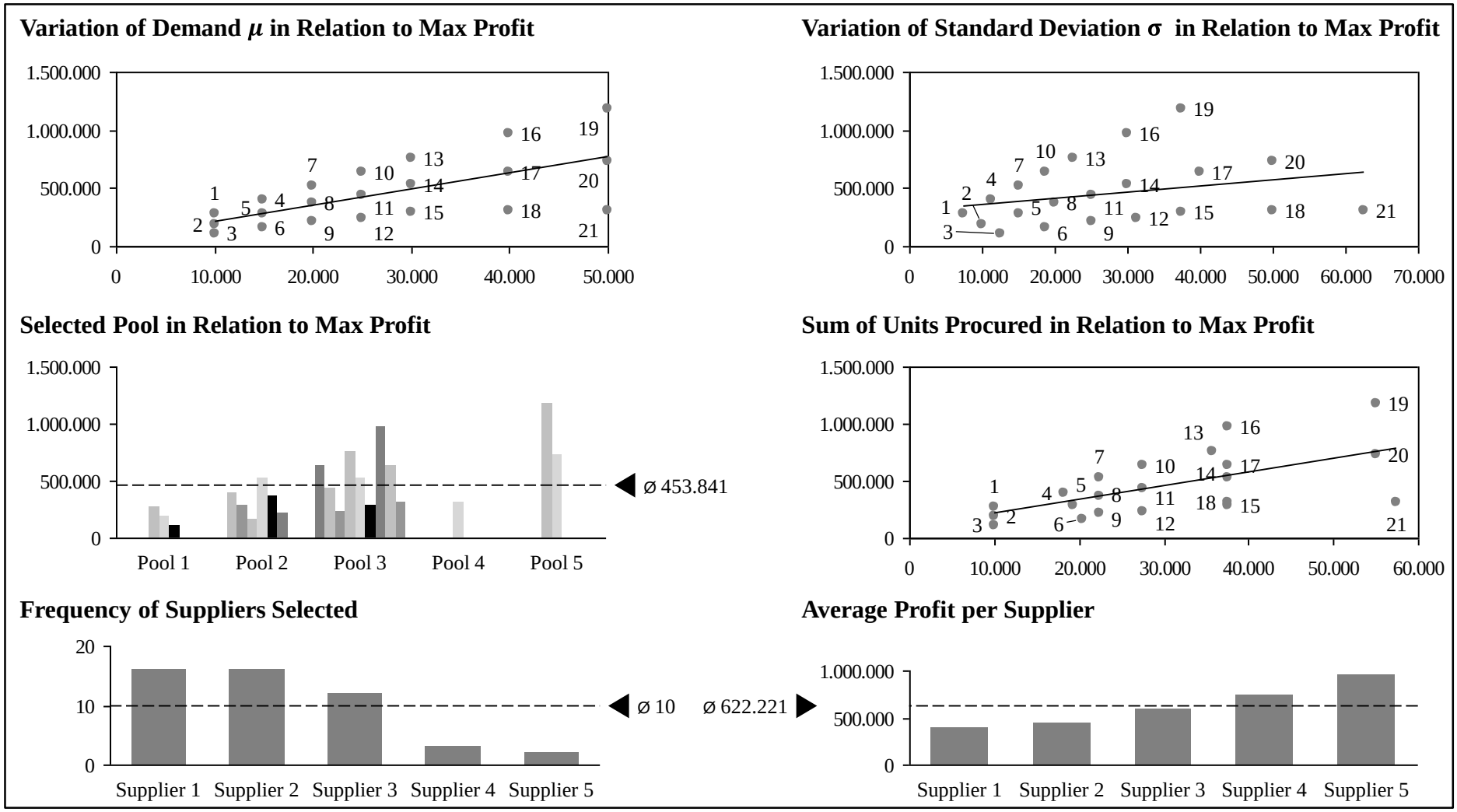


Figure IV-3: Overview of the general results of the Examples 1-21.

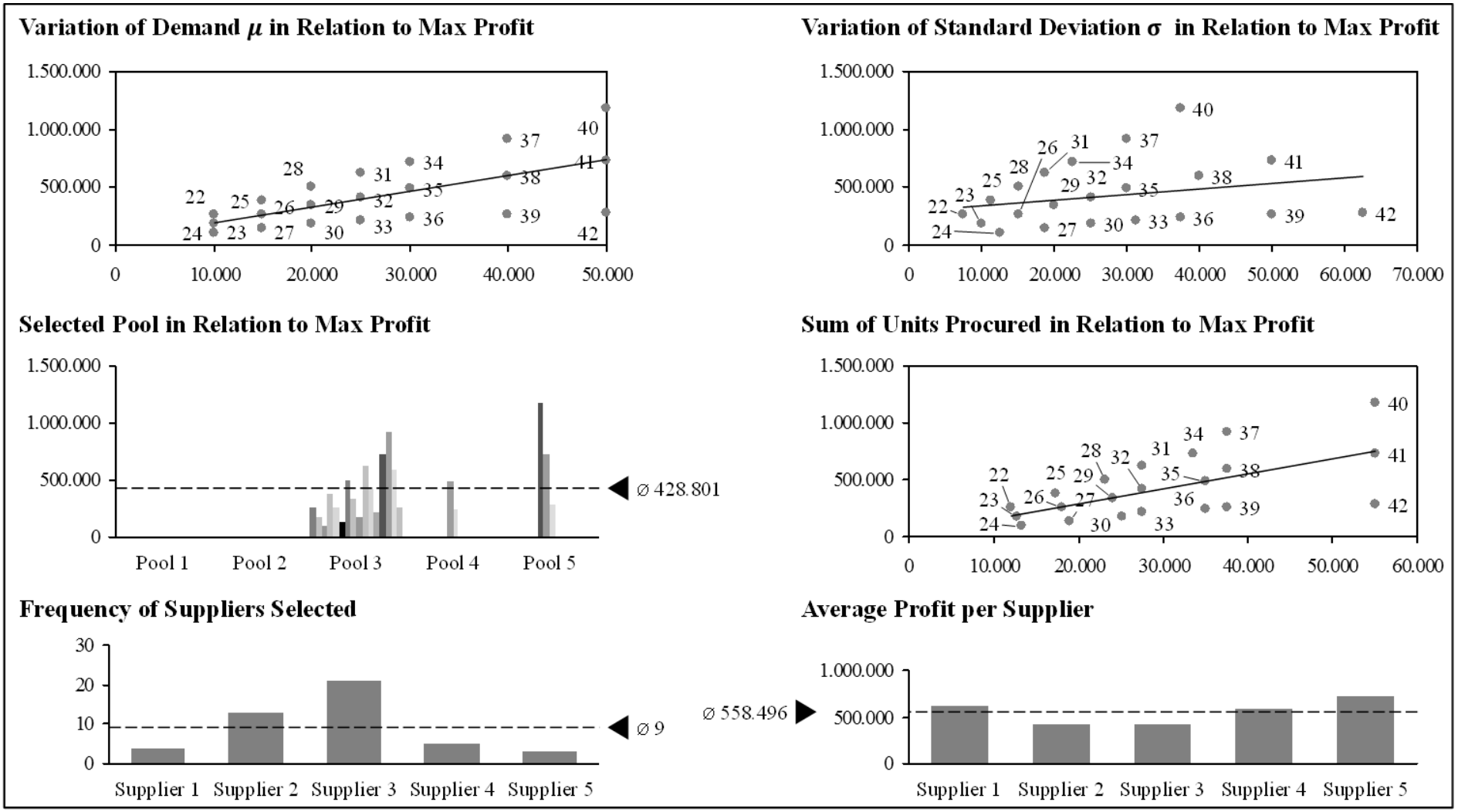


Figure IV-4: Overview of the general results of the Examples 22-42.

4.3.2 Results of Variation of Average Demand μ and Standard Deviation σ

We first present the findings for the Examples 1-21 where demand μ and standard deviation σ are varied while the other variables stay the same.

Solving our model using the data of Example 5, we find the value of the objective function equals $280,793 , i.e. the expected maximum profit. The decision variables are all zero with the exception of $z_2 = 1$ (choose pool 2), $u_{12} = u_{22} = 1$ (employ suppliers 1 and 2 of $S_2 = 1$ (suppliers 1 and 2 of S)), $x_2 = 19{,}303$ (main components procured in total), $y_{21} = 12{,}500$ (main components procured from supplier 1 of S_2 (supplier 2 of S)), $y_{22} = 6{,}803$ (main components procured from supplier 2 of S_2 (supplier 1 of S)), S_2 (supplier 1 of S)), and $v_{22} = 1$ (hence the expected reduction in profit due to unsold main components is calculated recognizing that units of the main component are procured from supplier 2 of S_2 (supplier 1 of S)).

In Example 5, using pool 2 instead of pool 1 brings a 4.5 percent reduction in the price for the manufacturer's end product (the price shrinks from $110 to $105) and increases fixed charges by 100 percent (fixed charges raise from $5,000 to $10,000). Nevertheless, using pool 2 instead of pool 1 allows the bulk of the main components to be procured for approximately 6.7 percent less per unit (the greater part of the components costs $35 instead of $37.50 each). Eventually, the model has determined it is optimal (in the sense of profit maximizing) for the manufacturer to procure main components from supplier 1 of S_2 (supplier 2 of S) up to its capacity limit and to procure an additional 6,803 main components supplier 2 of S_2 (supplier 1 of S), which all together equals Q_{22}, the newsvendor quantity for supplier 2 of S_2.

Table IV-4: Summary of results for $V_1 = \$7.50$ and $V_2 = \$2.50$.

Ex.	μ	σ	Pool	Units Procured	Sum of Units Procured	Profit
1	10,000	7,500	1	$y_{11} = 10{,}000$	10,000	$273,154
2	10,000	10,000	1	$y_{11} = 10{,}000$	10,000	$190,873
3	10,000	12,500	1	$y_{11} = 10{,}000$	10,000	$108,591
4	15,000	11,250	2	$y_{21} = 12{,}500,\ y_{22} = 5{,}728$	18,228	$397,157
5	15,000	15,000	2	$y_{21} = 12{,}500,\ y_{22} = 6{,}803$	19,303	$280,793
6	15,000	18,750	2	$y_{21} = 12{,}500,\ y_{22} = 7{,}879$	20,379	$164,429
7	20,000	15,000	2	$y_{21} = 12{,}500,\ y_{22} = 10{,}000$	22,500	$522,928
8	20,000	20,000	2	$y_{21} = 12{,}500, y_{22} = 10{,}000$	22,500	$369,940
9	20,000	25,000	2	$y_{21} = 12{,}500, y_{22} = 10{,}000$	22,500	$209,946
10	25,000	18,750	3	$y_{31} = 15{,}000, y_{32} = 12{,}500$	27,500	$632,525
11	25,000	25,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500$	27,500	$434,379
12	25,000	31,250	3	$y_{31} = 15{,}000, y_{32} = 12{,}500$	27,500	$232,562
13	30,000	22,500	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 8{,}200$	35,700	$762,453
14	30,000	30,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 10{,}000$	37,500	$528,797
15	30,000	37,500	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 10{,}000$	37,500	$288,045
16	40,000	30,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 10{,}000$	37,500	$968,566
17	40,000	40,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 10{,}000$	37,500	$640,295
18	40,000	50,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 10{,}000$	37,500	$311,681
19	50,000	37,500	5	$y_{51} = 20{,}000, y_{52} = 20{,}000, y_{53} = 15{,}000$	55,000	$1,175,619
20	50,000	50,000	5	$y_{51} = 20{,}000, y_{52} = 20{,}000, y_{53} = 15{,}000$	55,000	$729,791
21	50,000	62,500	4	$y_{41} = 20{,}000, y_{42} = 15{,}000, y_{43} = 12{,}500, y_{44} = 10{,}000$	57,500	$308,128

We now turn our attention to the rest of the examples in Table IV-4. For each example we provide the parameters of the log-normal demand model, the optimal pool to source from, the optimal quantity to procure from each supplier in the chosen pool (when other than zero), the optimal order quantity in total and the manufacturer's expected maximum profit. We consider examples where the coefficient of variation of demand ($\frac{\sigma}{\mu}$) varies from 0.75 to 1.00 or 1.25 in every triple that has the same average demand μ. Those triples of same average demand are Examples 1-3, 4-6, 7-9, 10-12, 13-15, 16-18, 19-21.

In the classical newsvendor problem, i.e. a single supplier problem without any capacity constraints or fixed charges, with increase of demand variability it becomes optimal to

increase stock quantities assuming the economics are attractive meaning the cost of underage is greater than the cost of overage. This correlation can only be confirmed in our Examples 4-6 (as described with the presentation of Example 5), 13-14 and 20-21.

In fact, our sourcing model – that embraces multiple suppliers with capacity constraints, fixed charges and different sustainability levels as determining optimum factor – reveals three impact factors that lead to a stocking behavior that is different to that expected in the classical newsvendor problem.

The first impact factor we expose is the suppliers' sustainability level that determine the manufacturer's end product price. In Examples 1-3, it can be seen that the stock quantity, i.e. the sum of units procured, is the same in each example with 10,000 components procured. As the economic environment is attractive in this setting, it would have been reasonable to expect higher stock levels in Examples 2 and 3 than in Example 1 because of increased demand variability (higher standard deviations in Examples 2 and 3). However, our model has determined that the benefit of increased stock going into the sales period does not outweigh the reduction of the end product price that would come with tapping another pool. Thus, despite higher demand variability, higher capacities provided by less sustainable suppliers from another pool do not always compensate the decrease in selling prices generated with these less sustainable suppliers. This phenomenon has been identified in addition to Examples 1-3 in Examples 7-9 and 16-18 where the whole capacity of the respective pool is consumed. But instead of switching to a pool with a higher capacity but a lower sustainability ranking in the given scenarios of increasing demand variability, the examples in the respective triples stay with procuring the same order quantities from a pool with a higher sustainability ranking. Hence, the impact of sustainability levels respectively end product prices on order quantities and finally maximum profit is the first factor we identify.

The second factor we determined to affect order quantities respectively maximum profit is fixed cost. Therefore, consider Examples 10-12 where the stock quantity again is the same in each example with 27,500 components procured. Given the economic environment is attractive, once more it would be rational to expect higher stock levels in Examples 11 and 12 than in Example 10 because of increased demand variability. Yet, our model detects that the benefit of increased stock going into the sales season does not outweigh the rise of additional fixed cost that would be incurred if supplier 3 of that pool was supplementary procured from. The impact of fixed cost can also be seen in Examples 19 and 20 where our model has determined that the increase in stocks does not outweigh the extra fixed charges that would occur if additionally supplier 4 and supplier 5 of the considered pool 5 were procured from. Accordingly, fixed cost is the second factor impacting stock quantities and thus maximum profit we determined in our examples.

The third impact factor on stock levels we identify is the coefficient of variation of demand $\frac{\sigma}{\mu}$. We find that when the coefficient of variation is greater than one and the average demand is greater than 20,000, it is unprofitable for the manufacturer to procure solely from supplier 1. In other words, if the manufacturer went into the sales period with just the 10,000 main components that supplier 1 is able to provide, then the expected profit of the manufacturer would be even negative, implying losses under the aforementioned conditions. This is valid for instance for Example 12 caused by a confluence of effects. One effect is that for this stock quantity, the probability of a demand realization where the entire stock is consumed is quite high (e.g. almost 70 percent in Example 12) on the one hand but simultaneously the probability of a demand realization where most of the demand goes uncaptured is also quite high (e.g. over 50 percent in Example 12), on the other hand. The other effect is because of the high level of demand uncertainty, the probability of a demand realization where demand is next to nil is not

insignificant (e.g. about 20 percent in Example 12). All in all, these effects imply that the manufacturer significantly misses out on sales, and hence, profits if the demand is high, while if the demand is low, the manufacturer ends up with piles of unsold inventory and financial losses. To be profitable under the aforementioned conditions, the manufacturer needs to go into the sales period with a higher stock quantity – by not solely procuring from supplier 1, but instead for instance in Example 12 from supplier 2 and supplier 3. This offers the manufacturer the opportunity to generate more sales if the demand is high and reduce losses due to lower component cost if the demand is low. This effect of the coefficient of variation of demand can likewise be noticed in Examples 15, 18 and 21: Here, the coefficient of variation is greater than one and the average demand is greater than 20,000 and thus it is unprofitable to solely acquire the components from supplier 1 due to the reasons described by means of Example 12. Accordingly, for the examples regarded here this demonstrates a certain need to source from less sustainable, cheaper suppliers to consider the impact of the coefficient of demand. Interestingly, for some of the examples it is even profitable to source from supplier 5, the supplier with the lowest sustainability ranking, but not from supplier 1, the supplier with the highest sustainability ranking. Thus, the analysis of the third impact factor identified, the coefficient of variation of demand, underlines the requirement for our model to maximize profit in complex sourcing decisions.

4.3.3 Results of Variation of Salvage Value V_j

Next we discuss the results of reducing the positive salvage values by around two third of their original values as carried out for the Examples 22-42 presented in Table IV-5.

The impact of all three previously identified factors that affect order quantities respectively maximum profit could be confirmed: The impact of the first factor, i.e.

suppliers' sustainability levels that determine the manufacturer's end product price, can be observed in Examples 37-39: The total capacity of the suppliers in pool 3 is consumed. However, the benefit of increasing sales capacity by switching to another pool does not outweigh the reduction of the end product price that comes along with the procurement from a less sustainable pool of suppliers.

The impact of the second factor identified, i.e. fixed cost that influence order quantities and thus maximum profit, can be noticed in Examples 31-33: Although there is an increase in demand variability, the benefit of raising sales capacity by supplementary procuring from supplier 3 of the same pool does not compensate the fixed cost that would then be charged additionally.

The impact of the third factor, the coefficient of variation of demand, can be noted in Examples 33, 36, 39 and 42: Here, the coefficient of variation is greater than one and the average demand is greater than 20,000, and thus it is unprofitable to solely procure from supplier 1 due to the explained reasons.

Nevertheless, the reduced salvage value has a remarkable influence that affect different results for the Examples 22-42 compared to the results for the Examples 1-21. Therefore, consider Examples 31-33 first. The supplier considered by the model but not added to the mix is supplier 1 of S as already exposed. Furthermore, it can be seen for the examples of Table IV-5 that there is a general aversion to use supplier 1. While in Examples 1-21, supplier 1 is part of the solution for sixteen times (in Examples 1-9, 13-18 and 21), now in Examples 22-42, supplier 1 is part of the solution only for four times (in Examples 34 and 37-39) (see Figure IV-3 and Figure IV-4). Clearly the reduction of supplier 1's salvage value in Examples 22-42 has made the use of supplier 1 unattractive in most situations although the supplier still has the highest salvage value among all suppliers in

addition to the highest sustainability ranking, which leads to the best end product pricing. Although the reduction in supplier 1's salvage value is higher than that of supplier 2 in absolute terms (supplier 1: reduction of \$4.86; supplier 2: reduction of \$1.63), the reduction in percentage terms is the same in both cases (reduction of 65 percent each). As such, one might expect supplier 2 to be similarly avoided, however this is not the case. Supplier 2 is part of a solution only three times less in Examples 22-42 than in Examples 1-21. This would suggest that intuition may be of limited value in complex sustainable sourcing problems, underscoring the need for our mathematical modeling approach.

Table IV-5: Summary of results for $V_1 = \$2.625$ and $V_2 = \$0.875$.

Ex.	μ	σ	Pool	Units Procured	Sum of Units Procured	Profit
22	10,000	7,500	3	$y_{31} = 12{,}018$	12,018	\$259,430
23	10,000	10,000	3	$y_{31} = 12{,}691$	12,691	\$180,073
24	10,000	12,500	3	$y_{31} = 13{,}363$	13,363	\$100,717
25	15,000	11,250	3	$y_{31} = 15{,}000, y_{32} = 2{,}327$	17,327	\$380,919
26	15,000	15,000	3	$y_{31} = 15{,}000, y_{32} = 3{,}102$	18,102	\$260,392
27	15,000	18,750	3	$y_{31} = 15{,}000, y_{32} = 3{,}878$	18,878	\$139,865
28	20,000	15,000	3	$y_{31} = 15{,}000, y_{32} = 8{,}102$	23,102	\$501,882
29	20,000	20,000	3	$y_{31} = 15{,}000, y_{32} = 9{,}137$	24,137	\$341,564
30	20,000	25,000	3	$y_{31} = 15{,}000, y_{32} = 10{,}171$	25,171	\$180,861
31	25,000	18,750	3	$y_{31} = 15{,}000, y_{32} = 12{,}500$	27,500	\$618,231
32	25,000	25,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500$	27,500	\$416,060
33	25,000	31,250	3	$y_{31} = 15{,}000, y_{32} = 12{,}500$	27,500	\$212,250
34	30,000	22,500	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 6{,}090$	33,590	\$723,256
35	30,000	30,000	4	$y_{41} = 20{,}000, y_{42} = 15{,}000$	35,000	\$488,271
36	30,000	37,500	4	$y_{41} = 20{,}000, y_{42} = 15{,}000$	35,000	\$238,585
37	40,000	30,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 10{,}000$	37,500	\$919,816
38	40,000	40,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 10{,}000$	37,500	\$591,545
39	40,000	50,000	3	$y_{31} = 15{,}000, y_{32} = 12{,}500, y_{33} = 10{,}000$	37,500	\$262,931
40	50,000	37,500	5	$y_{51} = 20{,}000, y_{52} = 20{,}000, y_{53} = 15{,}000$	55,000	\$1,175,619
41	50,000	50,000	5	$y_{51} = 20{,}000, y_{52} = 20{,}000, y_{53} = 15{,}000$	55,000	\$729,791
42	50,000	62,500	5	$y_{51} = 20{,}000, y_{52} = 20{,}000, y_{53} = 15{,}000$	55,000	\$282,773

5. Conclusions and Implications

The historical agreement on climate change in Paris in 2015 has recalled global attention for the relevant field of sustainability. Both academic and managerial research papers have considered the object of sustainability, e.g. in the context of sourcing. However, so far their main focus has been on conceptual models lacking quantitative sourcing models that incorporate environmental and social concerns. Therefore, we have developed a mathematical sourcing model that takes into account – for the first time to our knowledge – suppliers' sustainability levels as determining factor for the end product price and end product demand. As further new component, we have integrated supplier capacity constraints as well as the construct of a pool in our newsvendor model formulation.

5.1. Academic Contributions

We have developed a quantitative sustainable sourcing model for supplier selection and order allocation decisions. In detail, we have extended the classical newsvendor problem, i.e. a single supplier problem without any capacity constraints or fixed charges, and investigated a multiple supplier problem with capacity constraints, fixed charges and a sustainability component. Moreover, we have integrated the issue of sustainability holistically in a mathematical sourcing model. Thereby, we have introduced the demand for the end product as determined by different suppliers' sustainability levels in our quantitative sustainable sourcing model. Furthermore, we have treated the price the manufacturer obtains for its end product as a function of the sustainability of the suppliers the manufacturer uses to provide the main component. In doing so, we fill the lacuna in research on SSCM and in particular on sustainable sourcing as presented in section 2.

For the purpose of robustness and testing our model, we have run 33 sensitivity analyses with variations of the component price, salvage value and suppliers' capacity first. As expected, the salvage value has a positive impact on the profit, while the component price has a negative impact. Interestingly, the profit is indifferent to the suppliers' capacity explored in the context of a pool in our sensitivity analysis scenarios.

Hence, we have subsequently calculated the outcomes for 42 representative examples with our model to investigate more comprehensively the selection of a pool and certain suppliers. Thereby, we have identified three impact factors on order quantities and finally on profits that in parts counterbalance the impact of variation of demand described in the classical newsvendor model. The first impact factor is the suppliers' respectively pool's sustainability level that determines the end product price and thus profits. In contrast to the classical newsvendor model that says it would be optimal to have higher stocks with rising levels of uncertainty, our model has determined that the benefit of higher stocks does not always compensate the reduction of the end product price when switching to another, less sustainable pool. The second impact factor on the profits are fixed charges. Again contrariwise to the expectations of the classical newsvendor model, our model has found that the increase in stocks does not consistently offset the additional fixed charges that would incur if supplementary other suppliers in the same pool were procured from. The third impact factor is the coefficient of variation of demand ($\frac{\sigma}{\mu}$). Our model determined that if the coefficient of variation is greater than one and the average demand is greater than 20,000, it will be unprofitable to solely procure from supplier 1 as then the expected profits would be negative and the manufacturer would experience losses.

Eventually, the reduction of the salvage value to around one third of the original value in the second set of the examples has emphasized the need for our quantitative sustainable

sourcing model: Although all suppliers with positive salvage values had to deal with the same relative reductions of their salvage values, they have not been avoided to the same extent.

5.2. Managerial Implications

Besides the presented academic contributions, the model developed in this paper has also some managerial implications as shown by the representative examples.

First of all, our model can be used by a production manager of the described problem setting to select a mix of suppliers and determine order quantities to maximize the manufacturer's expected profit in the context of sustainability.

Furthermore, our model is not dependent on a specific definition of sustainability, which increases its applicability since sustainability seems to mean different things to different people as diverse surveys reveal, such as the study conducted by the MIT Sloan Management Review (Kiron et al., 2013). In order to use our model a manager simply needs to be able to rank suppliers from highest to lowest in terms of his own definition of sustainability.

Hence, our model can be used universally and contribute to achieve the ambitious targets of the climate change agreement of Paris in 2015.

5.3. Future Research

Our single period model can be extended to a multi-period model to account for more realistic effects since vendor planning usually considers a higher granularity. Moreover, the robustness of the model should be enhanced: Further research is needed to explore more deeply the impact of various parameter changes on the optimal sourcing pattern and

the manufacturer's expected profitability under the constraints of suppliers' sustainability levels. Finally, longer term research might study the setting of a long life cycle end product instead of our considered short life cycle product using our developed sustainable sourcing model formulation.

V. Summary and Conclusion

In this thesis, three interlinked essays explored the object of sustainable supply chain management. The thesis was driven by the motivation to investigate the question of how companies establish sustainability activities within their companies and along their supply chains and how this course can be advanced by models and tools. In doing so, different theoretical approaches were employed, such as institutional theory (DiMaggio and Powell, 1983; Glover et al., 2014), AHP (Kubicz et al., 2015; Saaty, 1990), TCO (Degraeve et al., 2000; Ellram 1993; Ellram and Siferd, 1998), and newsvendor theory (Pan, 1989; Awasthi et al., 2009; Zhang and Thang, 2011), and applied to the field of sustainability, i.e. the consideration of environmental, social, and economic issues (Elkington, 1998; Kleindorfer et al., 2005). Both qualitative, such as scenario-based experimental pre-tests followed by multiple case studies, and quantitative research methods, such as empirical mathematical tests with sensitivity analyses, were applied.

The first essay "Institutional pressures and responses in the field of sustainability: The moderating effects of expected sustainability benefits and top management support" focused on the investigation of companies' sustainability activities. Based on a multiple case study with eight companies in the manufacturing and service providing sectors, the results are as follows: First, evidence can be provided that different types of institutional pressures, i.e. coercive, mimetic, and normative pressures, affect companies to respond with isomorphic sustainability activities which results in average-sustainability pervasion levels. Second, the two moderators "expected sustainability benefits" and "top management support" are proposed to impact institutional pressures so that companies establish anisomorphic – the term is introduced in this essay as contrast to isomorphic –

sustainability activities which result in supra- respectively sub-sustainability pervasion levels. The findings are presented in an extended research model with testable propositions (Figure II-5 and Figure II-6). Concluding from the results, future research in the context of institutional theory applied to sustainability might extend this study and explore how institutional pressures in other sectors and countries affect companies' sustainability activities since there might be different reasons for coercive pressures, such as environmental regulations, and for normative pressures, such as social expectations.

Motivated by interviewees' requests of the first essay for a more practical model for sustainable decision making, the second essay "Towards integrated sustainable supplier selection with the total sustainability of ownership method" investigated the subject of sustainable supplier selection in detail. Derived from the concepts of AHP and TCO, the TSO model is developed to connect subjective functional perspectives with the suppliers' objective multi-dimensional sustainability performance measures. Based on an experimental pre-test and a multiple case study with three multinational companies in the high-tech sector, the results are as follows: First, the different sustainability criteria evaluations of the involved decision makers from multiple departments are explored. Second, both a conceptual and mathematical model for sustainable supplier selection is introduced (Figure III-1 and section III-3.2.). By proposing transitive relations, the complexity of the AHP method is reduced and its consistency increased (Figure III-6 and section III-3.1.4.). Thereby, the process of sustainable supplier selection in business practice can be facilitated. Based on the findings, future research might enhance the study by applying the developed AHP-TSO method to other contexts and sectors to foster a better alignment of the involved decision makers and thus contribute to the corporate business success.

Driven by the investigated complexity of sustainable supplier selection in the second essay, the third essay “A quantitative sustainable sourcing model for supplier selection and order allocation” considers this issue from a mathematical perspective to a greater extend with a focus on sustainable order allocation decisions. Based on the newsvendor model, the paper develops a linear programming model for sustainable sourcing decisions and introduces the end product demand and price as functions of the suppliers’ sustainability level. Founded in empirical tests of 42 scenarios and sensitivity analyses, the findings are as follows: First, higher order capacities do not always justify the switch to a less sustainable supplier pool since it entails a reduction in the end product’s price. Second, higher stocks do not constantly offset the additional fixed charges if additionally procured from other suppliers in the same pool. Third, in order to optimize profits, sustainability-sensitive demand and its coefficient of variation are to be considered in a sustainable supplier selection and order allocation decision (Figure IV-3, Figure IV-4, and section IV-4.3.). Our results have shown that future research may enhance the presented single to a multi-period model and further study the correlation of the parameter changes to enhance the robustness of the model.

Referring to the introduction of this thesis, the topic of sustainability is highly prevailing for the global society, such as politics, business and academic research. Since certain countries have recently announced to resign from the Paris climate contract in 2015, it is even more crucial to understand the mechanism of sustainability implementation and to develop effective tools to facilitate its establishment. This thesis has explored the subject of sustainable supply chain management and offered several models and tools to support

a higher sustainability pervasion in different contexts. Thereby, it can contribute to the targets of sustainability, i.e. the mentioned “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland Report, 1987).

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Appendix-Chapter II 1: Case Company Description*

1. *Alpha*

Alpha is one of the leading telecommunication service providers worldwide. In 2011, *Alpha* achieved a turnover of € 60,000 million, an EBIT of € 6,000 million, and employed 250,000 people. Together with its 130 million customers, *Alpha* actively engages in the object of sustainability by means of various programs.

2. *Beta*

Beta is a globally operating logistics and communications service provider. In 2011, *Beta* generated with 500,000 employees a turnover of € 50,000 million and an EBIT of € 2,500 million. *Beta* is committed to sustainability through programs focusing on climate protection, civil protection and education.

3. *Gamma*

Gamma has been one of the largest automotive manufacturers in the world for more than 100 years now. In 2011, *Gamma* had 300,000 employees and sold more than 2 million vehicles. Its revenue totaled € 110 billion and its EBIT amounted to € 10 billion. *Gamma* applies innovative and green technologies to produce safe and superior vehicles. For years, *Gamma* has consistently invested in the development of alternative drives with the aim of achieving emission-free mobility in the long term.

4. *Delta*

Delta is among the world's leading automotive manufacturers. In 2011, *Delta* had 100,000 employees, achieved a turnover of € 70,000 million and an EBIT of € 7,500 million. *Delta*

* All figures are rounded for anonymity purposes.

links profitability and long-term value in a changing environment – technologically, structurally and culturally.

5. *Epsilon*

Epsilon is one of the Europe's leading power and gas service providers. In 2011, *Epsilon* generated a turnover of € 110 billion and an EBIT of € 5.5 billion with 100,000 employees worldwide. In 2010, *Epsilon* introduced the target of clean energy to become a specialist in this field. *Epsilon* is among the largest companies by turnover in Germany. It has been listed in the DJSI World and DJSI Europe for the fourth time running.

6. *Zeta*

Zeta is among Europe's largest power and gas service providers. In 2011, *Zeta* achieved a turnover of € 50 billion, an EBIT of € 3 billion, and had 100,000 employees and 25 million customers. *Zeta*'s company strategy embraces the topic of sustainability with regards to climate protection and energy efficiency.

7. *Eta*

Eta is a large globally operating service provider in electrical and electronic engineering. With 400,000 employees, *Eta* generated a turnover of € 80 billion and an EBIT of € 7 billion in 2011. *Eta* focuses its sustainability commitment by developing new technologies in the energy and healthcare sector.

8. *Theta*

Theta is one of the world's leading chemical manufacturer. With about 100,000 employees, *Theta* generated a turnover of € 80 billion and an EBIT of € 8.5 billion in 2011. By means of new principles and technologies embracing sustainable development, *Theta* creates additional market opportunities with focus on the green sector.

Appendix-Chapter II 2: Presentation of the eight cases' details regarding figures, interviewees and departments.

Company*	***Alpha***	***Beta***	***Gamma***	***Delta***	***Epsilon***	***Zeta***	***Eta***	***Theta***
Revenue**	60,000	50,000	100,000	70,000	110,000	50,000	80,000	80,000
EBIT**	6,000	2,500	10,000	7,500	5,500	3,000	7,000	8,500
Employees	250,000	500,000	300,000	100,000	100,000	100,000	400,000	100,000
Sector	Service Provider	Service Provider	Manufacturer	Manufacturer	Service Provider	Service Provider	Manufacturer	Manufacturer
Interviewees***	7	7	4	3	4	2	2	6
Positions	• Head of Sustainable Procurement; • Strategic Sourcing Manager • Head of Corporate Responsibility • Head of Brand Strategy • Vice President Marketing • Product Innovation Manager • Product Manager	• Vice President Procurement Trucks • Procurement Manager Freight • Senior Expert Sustainable Supply Chain • Vice President Corporate Sustainability • Carbon Accounting Manager • Operations Manager • Investor Relations Manager	• Head of Sustainable Procurement • Corporate Social Responsibility Manager • Head of External Publications • Executive Communica-tions Manager	• Head of Sustainable Supply Chain Management • Corporate Sustainability Strategy Manager • Head of Corporate Health Care Management	• Executive Sustainable Procurement • Consulting Manager Products • Spokesperson Corporate Responsibility • Executive Innovations Management	• Head of Supplier Management • Head of Corporate Responsibility	• Executive Corporate Supply Chain Management • Head of External Sustaina-bility Office	• Head of Corporate Sustainability • Freelancer HR Controlling • R&D Assistant • Executive Safety Manager • Production Manager • Analytics Manager
Departments	• Procurement • CR • Marketing • R&D • Operations	• Procurement • CR • Operations • Finance	• Procurement • CR • Marketing	• Procurement • CR • HR	• Procurement • CR • R&D • Operations	• Procurement • CR	• Procurement • CR	• CR • HR • R&D • Operations • Finance

* Company figures as of 2011; all figures are rounded for anonymity purposes; ** Figures in million €; *** In total 35 interviewees;

Appendix-Chapter II 3: Environmental and social KPIs as a response to institutional pressures.*

	1. *Alpha*	2. *Beta*	3. *Gamma*	4. *Delta*	5. *Epsilon*	6. *Zeta*	7. *Eta*	8. *Theta*
				Environmental Data				
CO_2 emissions**	3,000,000	30,000,000	4,000,000	3,000,000	130,000,000	160,000,000	4,000,000	30,000,000
Alternative vehicles	n.a.	1,600	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
				Social Data				
Women in Management (present)***	25%	20%	10%	10%	15%	10%	10%	10 %
Women quota (target)	30% by 2015	30% for new positions	20% by 2020	No precise target	No precise target	20% by 2018	15 % by 2020	15 % by 2020
Sickness rate****	6%	5%	5%	5%	n.a.	4%	0.34	0,86
Workplace accidents ******	8	12,829	14.4	3,941	3.3	2.8	0.42	1,9

* Company figures as of 2011; all figures are rounded for anonymity purposes; **** In tones; *** Share of women in middle and upper management positions; **** Calculated through given health rates; Exceptions: *Eta* presents its occupational illness frequency rate (OIFR) per one million working hours; Theta counts per health performance index (HPI); ***** *Alpha* counts its accidents per 1,000 employees; *Beta* and *Delta* present the total number of work accidents; *Gamma* states the frequency of accidents per one million working hours; *Epsilon*, *Zeta*, *Eta* and *Theta* present their lost time injury frequency (LTIF) rates per one million working hours;

Appendix-Chapter II 4: Quotes from case companies on institutional pressures on sustainability leading to isomorphism.

Isomorphism (I/V)		
Institutional Pressures	**Codes**	**Original Quotes***
Coercive Pressures	**Obligatory Regulations**(2)(3)	"Additionally, there are many regulations and laws installed by the government we also have to comply with."(Head of Sustainable Procurement at *Alpha*) "There are especially in our business field strong requirements from the legislature, we are a strongly regulated market, that also in terms of sustainability has to fulfil strict regulations". (Executive Innovations Management at *Epsilon*) "Governmental requirements, especially concerning the environment, have to be complied with." (Head of Corporate Responsibility at *Alpha*) "There are government regulations and laws we have to comply with." (Head of Sustainable Procurement at *Gamma*) „Mainly through the support of politicians creating corresponding basic conditions – even though the topic of sustainability was originally evolved by the economy, the wood industry – sustainability can advance further. Though, public authorities also have to control and monitor compliance and implementation." (Corporate Social Responsibility Manager at Gamma) "The energy sector is a strictly regulated market; manifold governmental requirements exist of course also on the sustainability subject to be considered as a basic framework." (Spokesperson Corporate Responsibility at *Epsilon*) "The topic of recycling is becoming more and more important. There are laws introduced by the Federal Republic of Germany as well as by the European Union. For example, there is the so-called Waste Electrical and Electronic Equipment (WEEE) Directive that forces traders to tack back electronic waste." (Vice President Marketing at *Alpha*) "To generalize, all legislations are supposed to incentivize sustainability activities. There are rules on emission trading, labor security, energy consumption and gender politics *Theta* has to fulfil." (Executive Safety Manager at *Theta)* "Mainly with the support of political decision-makers through the creation of basic standards […] sustainability can advance. In this context, public authorities also have to control and monitor its realization." (Corporate Social Responsibility Manager at *Gamma)*

* Most quotes were translated from German to English; sub-categories of sustainability activities are marked as follows: (1) Employees, (2) Processes, (3) Organization, (4) Business Field;

		Isomorphism (II/V)
Mimetic Pressures	**Sustainability Trend**(3)	"Sustainability is a highly relevant strategic issue. As we have seen in other sectors, a fast implementation of sustainability implies that you can enter the market earlier than your competitors and thus you can achieve a strategic competitive advantage." (Head of Sustainable Supply Chain Management at *Delta*)
		"There is a certain trend towards the topic of sustainability in general." (Corporate Social Responsibility Manager at *Gamma*)
		"Of course, we also consider the object of sustainability in order to stay competitive on the market." (Head of Corporate Sustainabilityat *Theta*)
		"Our department does not have a direct interface with our company's customers, so we do not feel much pressure from them. But of course, customer expectations towards sustainability is one of the drivers for our sustainability activities." (Executive Innovations Management at *Epsilon*)
		"Sustainability is a huge growing market based on the four mega of trends globalization, urbanization, climate change, and population growth. Companies have to recognize these trends and have to align their company portfolios according to sustainability." (Head of External Sustainability Office at *Eta*):
		"With regards to cross-functional cooperation in the context of sustainability, we had to overcome serious conflicts in the past years." (Head of Corporate Responsibility of *Zeta*)
		"However, our competitors have started to engage in sustainability subjects. Thus, we have to catch up." (Consulting Manager Products at *Epsilon*)
	New Business Fields(4)	"*Delta* definitely takes a pioneering role in the field of sustainability: *Delta* has been investing in research on electric and hydrogen mobility for more than 40 years. In addition, we practice honest communication about sustainability activities and not greenwashing. We are concerned about our credibility and reputation which would otherwise suffer considerably if, for example, NGOs were able to prove the opposite. " (Head of Sustainable Supply Chain Management at *Delta*)
		"With our environmental product portfolio, *Eta* has generated sales of around € 30 billion in 2011. This corresponds to 40 percent of the total sales." (Head of External Sustainability Office at *Eta*)
		"To push the process of becoming a more sustainable company and society, we place our newly developed, sustainable, and alternative drive technologies first or preferably at our employees' disposal." (Head of Sustainable Procurement at *Gamma*)

		Isomorphism (III/V)
Normative Pressures	**Health & Safety**(1)	"In the field of health management, the main sustainability focus is on the social perspective. For instance, we derive measures for demographic developments such as elderly employees, retirement in the age of 67. Therefore, we offer seminars on sports, nutrition, and stress management – keyword 'healthy life'." (Head of Corporate Health Care Management at *Delta*)
		"We offer a broad health care program. For instance, we have started the initiative "Move" and organize a sports event for our apprentices annually." (Executive Corporate Supply Chain Management at *Eta*)
		"We constantly monitor our processes on security aspects and to identify possibilities to improve and optimize them. There is a fixed, standardized security plan. Every five years, external inspectors check our security standards." (Production Manager at *Theta*)
	Internal Training Courses(1)	"We frequently conduct training courses with our employees regarding sustainability aspects. For example, our drivers get specific training for lower fuel consumption. At the beginning, there is verifiably a significant reduction. Unfortunately, the half-life of a better driving mode lasts only four to six weeks. Hence, we have to repeat those training courses regularly to ensure sustainability success." (Vice President Procurement Trucks at Beta)
		"I can choose whatever training course I am interested in; obviously I would only choose workshops that are relevant for my position. Theta pays for all of them." (Production Manager at *Theta*)
	External Consultants (3)	"Oh, by the way, beginning next week, an external consultant will come and work here at our department for several weeks to support us in implementing sustainability aspects in our newly designed corporate procurement strategy" (Head of Sustainable Procurement at *Alpha*)"
	Workshops with Supp-liers(3)	"We frequently train our suppliers through workshops on the topic of sustainability." (Head of Sustainable Procurement at *Gamma*)
		"Sustainability is an important issue for all of our stakeholders and recorded in our stakeholder management program. Every three years, we organize 'Sustainable Supplier Days' to intensively discuss the object of sustainability. This year, for the first time, it will take place in China where lots of our suppliers are located." (Head of Corporate Responsibility at *Alpha*)

Isomorphism (IV/V)	
Conferences(3)	"My participation at the UN world summit in Johannesburg was a personal highlight. The conference was really productive: As a representative of Delta, I took part in several workshops to discuss topics such as efficient production, new technologies, waste management and social responsibility and discussed those new concepts not only with representatives of the automotive sector but with representatives of various industries." (Head of Sustainable Supply Chain Management at *Delta*)
	"Especially the participation at the UN climate summit in Cancun, Mexico, was a special event for me. It was very inspiring and made me even more aware of this important and urgent topic. Based on this meeting, I had many new inputs that I implemented in our firm." (Head of External Sustainability Office at *Eta*)
Cooperation(3)	"We have certain sustainability R&D alliances with our competitors, e.g. to develop hybrid engines etc." (Executive Communications Manager at *Gamma*).
	"We run those supplier trainings integrating the aspect of sustainability in cooperation with other OEMs which are our competitors." (Head of Sustainable Procurement at *Gamma*)
	"We strive to cooperate with local units in other regions – that is crucial as the success of certain international sustainability programs depends decisively on successful cooperation" (Head of Corporate Health Care Management at *Delta*)
	"We have established a so-called 'Green Partnership' with a huge Indian company very similar to *Eta* regarding its size and business sector. This 'Green Partnership' with that firm means we agreed to cooperate in diverse green areas, for instance in the field of energy or mobility. In practice, engineers from both firms work together in teams to develop joint sustainable solutions. That is a new kind of cooperation with a customer under the umbrella of sustainability that works extremely well." (Head of External Sustainability Office at *Eta*)
Green Commitment(3)	"We have launched a special social media project in interaction with our customers: You have to upload a picture of you hugging a tree on a social network (e.g. Facebook) and then we donate € 1 to the German Environmental Aid Association. By doing so, we have planted our own '*Alpha* forest' with more than 1,000 planted trees." (Head of Brand Strategy at *Alpha*)
	"Likewise we want to push our customers actively to behave in more environmentally responsible ways. Therefore, we offer for example driver training classes to learn fuel-efficient driving." (Corporate Sustainability Strategy Manager at *Delta*)

	Isomorphism (V/V)
Social Commitment(3)	"In 2011, we celebrated our 125th company anniversary and accordingly supported 125 social projects with € 5,000 each." (Head of External Publications at *Gamma*)
	"We like other blue chip companies, too – do a lot corporate sponsoring in environmental, cultural and educational issues. For instance, we support kindergartens, donate wheelchairs or create tree planting projects " (Executive Communications Manager at *Gamma*)
	"Our executive managers volunteer in social facilities on-site once a year. Other employees also have the opportunity to be temporarily released from work to become actively involved in sustainability projects." (Consulting Manager Products at *Epsilon*)
	"Based on positive reactions, we have launched many sustainability projects linked with certain incentives to actively involve our customers and people in general in social projects as a call for support of "Ein Herz für Kinder", bone marrow donations or food donations for the "Tafel" in Germany." (Head of Brand Strategy at *Alpha*)
	"In cooperation with the International Bank for Reconstruction and Development, commonly known as World Bank, we have started an anti-bribery budget of € 100 million to support anti-bribery projects, e.g. during the infrastructure construction phase for the Olympic Games and the Football World Championship in Brazil. So far, the experiences we have made with this approach have been quite good, even though the project has only just begun." (Head of External Sustainability Office at *Eta*)
	"As a corporate citizen we have a responsibility towards society and must participate proactively. Hence, on our agenda there are topics such as AIDS that we address in our plants in affected regions. Other topics are for instance road safety problems embracing social and ecological issues." (Head of Sustainable Procurement at *Delta*)

Appendix-Chapter II 5: Quotes from case companies on moderators of institutional pressures on sustainability leading to anisomorphism.

Anisomorphism (I/IV)		
Moderators	**Codes**	**Original Quotes***
Expected Sustainability Benefits	**Moderating Coercive Pressures**(3)(4) (I/II)	"Of course, there are regulations we have to fulfill. However, we have recognized that this can be an advantage for us: With our core business, we can contribute to climate protection through dematerialization and digitization. For example, with the help of our services, business trips with aircrafts can be substituted by video conferences, hardware and thus material can be saved through our cloud services, and paper consumption can be reduced through digital formats. Thus, both we and the environment can benefit through our activities." (Head of Brand Strategy at *Alpha*)
		"In addition to the regulatory emission limits, we also have internally established CO_2 emission threshold values in our green travel and green car policy. This embraces a bonus respectively penalty system with regards to compliance with these thresholds. The penalty payments are donated to social and environmental projects." (Head of Corporate Responsibility at *Alpha*)
		"It is crucial to create transparency, to identify the consequences of unsustainable actions. For example with our smart meter project CO_2 emissions and energy consumption is visualized. However, new technologies must be promoted by the government. The constructions for the network expansion has been delayed due to civil protests. These so-called 'angry citizens' are a big obstacle. They have to be informed in detail and the benefits of the project have to be discussed broadly." (Executive Innovations Management at *Epsilon*)
		"We have sustainability campaigns that target on our customers. For instance, we have strengthened our marketing activities to promote our environmental products and services such as our energy efficiency program which we sell as a consulting service to our customers." (Head of External Sustainability Office at *Eta*)
		"Customers have an increased interest in environmentally friendly products. Therefore, we need certain environmental certificates. Hence, we additionally invest in green projects such as wind energy parks in China, waste incineration plants in Turkey or efficient household appliances in Africa. Through these activities, we improve people's lives and help reduce emissions. As a result, we obtain certain CO_2 certificates, so we can offer zero emission services to our customers. It's a real business model." (Vice President Procurement Trucks at *Beta*)

* Most quotes were translated from German to English; sub-categories of sustainability activities are marked as follows: (1) Employees, (2) Processes, (3) Organization, (4) Business Field;

	Anisomorphism (II/IV)
Moderating Coercive Pressures(3)(4) (II/II)	"As the market leader in Germany and one of the big players in Europe, we have the responsibility to push topics such as sustainability. I believe we are a pioneer in sustainability, as the introduction of a women's quota shows. Through our initiative, a broad discussion on the quota has started across all levels of society."(Vice President Marketing at *Alpha*) "Regarding the network construction, there are strong regulations by the federal network agency on the one hand. On the other hand, there is resistance by the population especially to new power cable constructions above ground. These conflicts e.g. with citizens' initiatives substantially impede those investments. For instance, planning for new network construction was done in 2002, but extensive approval procedures and court decisions deferred everything so that construction could not start until 2011." (Consulting Manager Products at *Epsilon*)
Moderating Mimetic Pressures(3)(4) (I/II)	"In our sector, I think we are among the top sustainability performers, if not the leading company. Of course, this always depends on the benchmarks, but we have very good sustainability programs. We were the ones who have developed the sustainability market. Nowadays, our competitors imitate us and launch almost identical products compared to our sustainability products – on the market but with other labels." (Vice President Corporate Sustainability at *Beta*) In our department, we consider the topic of sustainability for around five years. In contrast, our large competitors have neglected the topic to a great extent. They just have started to deal with the object. Thus, in our sector, we are the pioneering company for sustainability. (Product Manager at *Alpha*) "In Germany, public and political pressures increasingly force the industry to deal with the topic of sustainability. Primarily, however, sustainability is about identifying future risks – such as on energy, climate, resource scarcity, air pollution, water pollution – at an early stage. This offers new opportunities for exploring new business fields. For instance, water treatment is a new business field of *Theta* since water is becoming a scarce resource." (Freelancer HR Controlling at *Theta*) "Recycling is a common trend, many are doing that. We, however, have created a business model based on that: We collect all our used papers and paperboards and sell it for fixed prices per ton. There is a huge market for that as the Chinese are buying it." (Head of Sustainable Procurement at *Alpha*)

		Anisomorphism (III/IV)
	Moderating Mimetic Pressures[(3)(4)] (II/II)	"Sustainability is a subject we consider in our investment decisions, for example, through extensively testing the materials to be used. However, the trade-off costs versus sustainability is finally a decision of financial optimization." (Consulting Manager Products at *Epsilon*) "As example for our genuine sustainability realization I want to mention the following: Two or three years ago […], we tried to launch a mobile phone with sustainability aspects as its USP. It was based on solar cells as accumulator and the whole package was 100 percent recyclable. Despite that, this mobile phone was no market success, customers simply did not want that kind of product at that time." (Vice President Marketing at *Alpha*) "Yes, sustainability is an issue gaining more and more in relevance. However, we have to think about ourselves first and by engaging in sustainability we would have to abandon other more profitable fields of business and to instead invest huge amounts of euros to build up a less lucrative business segment." (Head of Supplier Management at *Zeta*)
Top Management Support	**Moderating Normative Pressures**[(1)(3)] (I/II)	"I guess it is very motivating, when there are good examples from the top of the hierarchy. Top management has to act as a role model, this drives the implementation of sustainability." (Head of Sustainable Procurement at *Gamma*) "We want more open discussion, also on the topic of sustainability, and no longer strict top-down-leadership." (Production Manager at *Theta*) "We anchor sustainability objectives in the target agreements of managers and thus create an incentive systems. Top management function as role model, which is incredibly important also for our corporate credibility." (Vice President Corporate Sustainability at *Beta*) "We train our executive managers on the topic of sustainability. Subsequently, they act as mediators and role models for their employees they are responsible for." (Head of Corporate Health Care Management at *Delta*) "From time to time, our executives work in social institutions to become committed to the object of sustainability." (Product Manager at *Epsilon*) "There is this 'By bike to work' initiative, which supports employees financially when they cycle to work. There are also executive managers doing that, they act as a model for a healthy life style and protection of the environment." (Carbon Accounting Manager at *Beta*)

		Anisomorphism (IV/IV)
	Moderating Normative Pressures(1)(3) (II/II)	"Well, of course the implementation of corporate sustainability is driven by our clients as well as by legislation. Above all, however, it is driven by our own willingness, from top manager to blue-collar worker." (Executive Safety Manager at *Theta*)
		"We have introduced a change management program with the target to create awareness of sustainability for every employee. Our hope is that sustainable behavior is not only shown because it is anchored in the target agreement, but on own personal initiative. In doing so, we have achieved good results, especially in the field of leadership." (Head of External Sustainability Office at *Eta*)
		"Unfortunately, the financial aspect often finally determines our decisions – I do not know the position of our CEO on that topic, I have not spoken to him." (Head of Supplier Management at *Zeta*)
		"All other marketing projects had to suffer from budget cuts except our sustainability campaign as this subject is a special concern of our CEO and is therefore supported explicitly by himself." (Head of Brand Strategy at *Alpha*)
		"Sustainability is linked with the idea of a respectable merchant represented by the CEO. You should only do things which you want to read in the newspaper about you, namely to act socially conscious and to work efficiently." (Carbon Accounting Manager at *Beta*)

Appendix-Chapter III 1: The random consistency index (RI) is determined by the number of criteria under evaluation (Deng, 2017).

Number of Criteria	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

Appendix-Chapter III 2: Second step of suppliers' sustainability measurements: Assessment of suppliers' sustainability performances ($\boldsymbol{SP}$).

		Suppliers' Sustainability Performance ($\boldsymbol{SP}$)				
Sub-Criteria	**Measures**	**Supplier 1**	**Supplier 2**	**Supplier 3**	**Supplier 4**	**Supplier 5**
Emissions	CO_2-equivalent in gram per unit	3	4	3.5	5.5	4.2
Energy	Energy in kilowatt-hour per unit	0.2	0.24	0.4	0.2	0.4
Waste	Weight in tons per unit	0.8	0.6	0.9	1.1	1.2
Price	Initial price in Euro per unit	4.5	4.08	2.75	4.8	4
Quality	Deficit goods in parts per million	70	30	43	10	90
Time	Error rate reliability in percent of deliveries	0.03	0.05	0.05	0.09	0.06
Security	Number of work accidents per year	24	2	8	12	9
Code of Conduct	Implementation of CoC on binary scale*	1	2	2	1	1
Compliance	Risk assessment on scale of 1-to-10**	1	1	1	1	1

* yes=1; no=2; ** 1= no risk; 10 = high risk

Appendix-Chapter III 3: Third step of suppliers' sustainability measurements: Calculation of scaled inverse sustainability performances ($\boldsymbol{SISP}$).

		Suppliers' Scaled Inverse Sustainability Performances ($\boldsymbol{SISP}$)				
Sub-Criteria	**Arithmetic Mean**	**Supplier 1**	**Supplier 2**	**Supplier 3**	**Supplier 4**	**Supplier 5**
Emissions	4.04	1.35	1.01	1.15	0.73	0.96
Energy	0.29	1.44	1.20	0.72	1.44	0.72
Waste	0.92	1.15	1.53	1.02	0.84	0.77
Price	4.03	0.89	0.99	1.46	0.84	1.01
Quality	48.60	0.69	1.62	1.13	4.86	0.54
Time	0.06	1.87	1.12	1.12	0.62	0.93
Security	11.00	0.46	5.50	1.38	0.92	1.22
CoC	1.40	1.40	0.70	0.70	1.40	1.40
Compliance	1.00	1.00	1.00	1.00	1.00	1.00

Appendix-Chapter III 4: Fourth step of suppliers' sustainability measurements: Multiplication of criteria vector (exemplary criteria vector of Procurement, *Beta*) by suppliers' performance matrix (integrated AHP-TSO method).

Criteria Vector		Suppliers' Scaled Inverse Sustainability Performance ($SISP$) Matrix						Suppliers' Scaled Inverse Sustainability Performances Weighted by Procurement ($WSISP_{Proc.}$)				
Procure-ment		**Supplier 1**	**Supplier 2**	**Supplier 3**	**Supplier 4**	**Supplier 5**		**Supplier 1**	**Supplier 2**	**Supplier 3**	**Supplier 4**	**Supplier 5**
2%		1.35	1.01	1.15	0.73	0.96		0.02	0.02	0.02	0.01	0.02
13%		1.44	1.20	0.72	1.44	0.72		0.18	0.15	0.09	0.18	0.09
13%		1.15	1.53	1.02	0.84	0.77		0.15	0.20	0.13	0.11	0.10
15%		0.89	0.99	1.46	0.84	1.01		0.13	0.14	0.21	0.12	0.15
15%	**x**	0.69	1.62	1.13	4.86	0.54	⇨	0.10	0.24	0.16	0.71	0.08
11%		1.87	1.12	1.12	0.62	0.93		0.20	0.12	0.12	0.07	0.10
16%		0.46	5.50	1.38	0.92	1.22		0.08	0.90	0.23	0.15	0.20
9%		1.40	0.70	0.70	1.40	1.40		0.13	0.06	0.06	0.13	0.13
7%		1.00	1.00	1.00	1.00	1.00		0.07	0.07	0.07	0.07	0.07
							Σ	1.06	1.90	1.10	1.55	0.93

Appendix-Chapter III 5: Results of fourth and fifth steps of suppliers' sustainability determination: Suppliers' $\boldsymbol{WSISP}$ by departments of *Beta* and the aggregated final supplier ranking.

	Suppliers' $WSISP$ by Departments				Final Supplier Ranking
	Procurement	**Logistics**	**Production**	**R&D**	
Supplier 1	1.1	1.1	1.1	1.1	**4.4**
Supplier 2	1.9	1.5	2.2	1.7	**7.3**
Supplier 3	1.1	1.1	1.1	1.1	**4.4**
Supplier 4	1.5	2.1	1.5	1.6	**6.7**
Supplier 5	0.9	0.8	0.9	0.9	**3.6**

Appendix-Chapter III 6: Detailed results of the sustainability weights of the three cases*:* *Alpha* (high-tech industry, ICT sector; ten participants, five departments), *Beta* (high-tech industry, automotive sector; four participants, four departments), and *Gamma* (high-tech industry, automotive sector; four participants, four departments).

Alpha

	Procurement	Logistics	Production	R&D	CR	Criteria Weights
Environmental	19%	7%	34%	33%	38%	**26%**
Economic	56%	71%	44%	56%	17%	**49%**
Social	25%	22%	22%	11%	45%	**25%**
Emissions	4%	5%	3%	10%	25%	**9%**
Energy	1%	1%	20%	13%	8%	**9%**
Waste	14%	1%	11%	10%	5%	**8%**
Price	37%	21%	15%	5%	7%	**17%**
Quality	7%	7%	28%	50%	7%	**20%**
Time	12%	43%	1%	2%	3%	**12%**
Security	8%	14%	21%	3%	17%	**13%**
Code of Conduct	10%	5%	1%	4%	14%	**7%**
Compliance	7%	4%	1%	4%	13%	**6%**

Beta

	Procurement	Logistics	Production	R&D	Criteria Weights
Environmental	27%	38%	26%	31%	**31%**
Economic	40%	52%	42%	36%	**42%**
Social	33%	10%	32%	33/	**27%**
Emissions	2%	3%	5%	2%	**3%**
Energy	13%	3%	6%	15%	**9%**
Waste	13%	31%	15%	15%	**18%**
Price	15%	3%	5%	10%	**8%**
Quality	15%	31%	15%	15%	**19%**
Time	11%	17%	22%	11%	**15%**
Security	16%	3%	22%	11%	**13%**
Code of Conduct	9%	3%	5%	10%	**7%**
Compliance	7%	3%	5%	11%	**7%**

Gamma

	Procurement	Logistics	Production	R&D	Criteria Weights
Environmental	32%	30%	27%	19%	**27%**
Economic	37%	38%	40%	50%	**41%**
Social	32%	32%	33%	31%	**32%**
Emissions	2%	2%	2%	3%	**2%**
Energy	16%	14%	13%	1%	**11%**
Waste	14%	14%	13%	16%	**14%**
Price	16%	6%	15%	21%	**14%**
Quality	16%	16%	15%	18%	**16%**
Time	5%	16%	11%	10%	**11%**
Security	16%	16%	16%	3%	**13%**
Code of Conduct	11%	14%	9%	8%	**10%**
Compliance	5%	2%	7%	21%	**9%**

Appendix-Chapter III 7: Analysis of criteria weights by department.

	Procurement		Logistics		Production		R&D		CR	
	Weights	Ranks	Weights	Ranks	Weights	Ranks	Weights	Ranks	Weights	Ranks
Environmental	26%		25%		29%		28%		38%	
Economic	44%		54%		42%		47%		17%	
Social	30%		22%		29%		25%		45%	
Emissions	3%	9	3%	8	3%	9	5%	9	25%	**1**
Energy	10%	6	6%	7	13%	3	10%	5	8%	5
Waste	13%	2	15%	3	13%	4	13%	2	5%	8
Price	22%	**1**	10%	5	12%	5	12%	4	7%	**7**
Quality	12%	4	18%	2	19%	2	28%	**1**	7%	6
Time	10%	7	25%	**1**	11%	6	8%	6	3%	9
Security	13%	3	11%	4	20%	**1**	6%	8	17%	2
Code of Conduct	10%	5	7%	6	5%	7	7%	7	14%	3
Compliance	7%	8	3%	9	4%	8	12%	3	13%	4

Appendix-Chapter III 8: Results of the suppliers' weighted scaled inverse sustainability performances (*WSISP*) by department and the final supplier ranking of each of the three cases (*Alpha, Beta, Gamma*).

Alpha

	Suppliers' *WSISP* by Departments					Final Supplier Ranking
	Procurement	**Logistics**	**Production**	**R&D**	**CR**	
Supplier 1	1.1	1.3	0.9	1.0	1.1	**5.3**
Supplier 2	1.5	1.7	2.2	1.5	1.8	**8.7**
Supplier 3	1.2	1.2	1.1	1.1	1.1	**5.7**
Supplier 4	1.2	1.1	2.1	2.9	1.3	**8.5**
Supplier 5	1.0	1.0	0.8	0.7	1.0	**4.6**

Beta

	Suppliers' *WSISP* by Departments				Final Supplier Ranking
	Procurement	**Logistics**	**Production**	**R&D**	
Supplier 1	1.1	1.1	1.1	1.1	**4.4**
Supplier 2	1.9	1.5	2.2	1.7	**7.3**
Supplier 3	1.1	1.1	1.1	1.1	**4.4**
Supplier 4	1.5	2.1	1.5	1.6	**6.7**
Supplier 5	0.9	0.8	0.9	0.9	**3.6**

Gamma

	Suppliers' *WSISP* by Departments				Final Supplier Ranking
	Procurement	**Logistics**	**Production**	**R&D**	
Supplier 1	1.0	1.1	1.1	1.1	**4.3**
Supplier 2	1.9	1.9	1.9	1.3	**7.0**
Supplier 3	1.1	1.1	1.1	1.1	**4.4**
Supplier 4	1.6	1.6	1.5	1.6	**6.4**
Supplier 5	0.9	0.9	0.9	0.9	**3.7**

Appendix-Chapter IV 1: Data for Example 5.

Data for Example 5*

- $\mu = \{15000,15000,15000,15000,15000\}$
- $\sigma = \{15000,15000,15000,15000,15000\}$
- $P = \{\$110, \$105, \$102.50, \$100, \$100\}$
- $D = \{\$20\}$
- $R = \{\$90, \$85, \$82.50, \$80, \$80\}$
- $C = \{\$37.50, \$35, \$32.50, \$32.50, \$32.50\}$
- $V = \{\$7.50, \$2.50, \$0, -\$5, -\$10\}$
- $F = \{\$5000, \$5000, \$2500, \$1000, \$0\}$
- $L = \{10000,12500,15000,20000,20000\}$
- $S_1 = \{1\}$
- $S_2 = \{2,1\}$
- $S_3 = \{3,2,1\}$
- $S_4 = \{4,3,2,1\}$
- $S_5 = \{5,4,3,2,1\}$
- $Q_{11} = 20231.3$

  $Q_{21} = 19036.0$, $Q_{22} = 19303.4$

  $Q_{31} = 19036.0$, $Q_{32} = 18558.0$, $Q_{33} = 18800.2$

  $Q_{41} = 17219.8$, $Q_{42} = 18558.0$, $Q_{43} = 18053.2$, $Q_{44} = 18267.0$

  $Q_{51} = 16045.3$, $Q_{52} = 17219.8$, $Q_{53} = 18558.0$, $Q_{54} = 18053.2$, $Q_{55} = 18267.0$
- $I_{11} = 3814$

  $I_{21} = 4817$, $I_{22} = 8380$

  $I_{31} = 5984$, $I_{32} = 7931$, $I_{33} = 8075$

  $I_{41} = 7159$, $I_{42} = 7931$, $I_{43} = 7634$, $I_{44} = 7759$

  $I_{51} = 6521$, $I_{52} = 7159$, $I_{53} = 7931$, $I_{54} = 7634$, $I_{55} = 7759$
- $E_{11} = \$314,617$

  $E_{21} = \$397,407$, $E_{22} = \$657,369$

  $E_{31} = \$493,691$, $E_{32} = \$645,389$, $E_{33} = \$666,209$

  $E_{41} = \$608,533$, $E_{42} = \$674,111$, $E_{43} = \$648,911$, $E_{44} = \$659,515$

  $E_{51} = \$586,917$, $E_{52} = \$644,350$, $E_{53} = \$713,764$, $E_{54} = \$687,083$,

  $E_{55} = \$698,310$

* For the parameters the subscripts are partly omitted and instead used to denote the entire vector.

Statement

I declare on my word of honor, that I am the sole author of this thesis. The exceptions to this are the sections for which one or more co-authors were involved; these sections are explicitly identified and the names of the co-authors are completely and truthfully listed. I confirm that I made a significant contribution to the sections for which one or more co-authors were involved that justifies my own co-authorship. The work was completed using only the cited sources. All information taken directly from source material or ideas based on information taken from source material have been clearly identified through the cited references.

Michaela Schöll

Berlin, 31 July 2017