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David Wittstruck, Frank Teuteberg

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David Wittstruck

Institute of Information Management and Corporate Governance, Research Group in Accounting and Information Systems, University of Osnabrueck, Katharinenstraße 1, 49069 Osnabrueck, Germany
+ 49 541 969-4523
david.wittstruck@uni-osnabrueck.de

Frank Teuteberg

Institute of Information Management and Corporate Governance, Research Group in Accounting and Information Systems, University of Osnabrueck Katharinenstraße 1, 49069 Osnabrueck, Germany
+ 49 541 969-4961
frank.teuteberg@uni-osnabrueck.de

Abstract. In recent years numerous publications in the field of Supply Chain Management have dealt with partner selection methods. So far, research has failed to offer a holistic approach for the selection of recycling partners that accounts for financial, social and environmental factors. In view of this fact, our article aims at developing an integrated multi-criteria decision model (MCDM) that supports recycling partner selection in the electrics and electronics industry. Based on a systematic literature review we identify limitations of existing approaches and design an integrated Fuzzy-AHP-TOPSIS model. In addition, relevant criteria for sustainable partner selection are determined. The approach is illustrated by means of an exemplary case study.

Keywords: Sustainable Supply Chain Management, Partner Selection, Supplier Selection, Recycling, AHP, Fuzzy, TOPSIS, Multi Criteria Decision Making

1 INTRODUCTION

In view of the constantly increasing global volume of electronic waste more and more companies are joining recycling networks based on multilateral business-to-business contracts to ensure secure waste disposal on a mid-term or long-term basis. These networks are facing a variety of challenges, as e.g. a multitude of (new) legal environmental demands and regulations (WEEE, RoHS Directive) as well as norms and standards (Energy Star Computer Program), extended reporting and publishing requirements (Sustainability Index, EMAS) and a shortage of natural resources. On top of this come the growing public interest in environmental protection (Green Logistics) and the employers' obligation to treat their staff responsibly (e.g. Ethical Trading Initiative (ETI) and Supplier Ethical Data Exchange (SEDEX)) – for example, employees must be sufficiently protected from the impact of hazardous substances (PVC, chlorine-containing PCBs). Therefore, in order to achieve a balance between social and environmental goals on the one hand and the need for long-term profitability on the other hand, the management of recycling networks needs to draw on adequate methods, technologies, information and communication systems. In response to the general call for a more sustainable economy (cf. Carter and Rogers, 2008; Seuring and Müller, 2007) Sustainable Supply Chain Management (SSCM) extends the traditional concept of Supply Chain Management by adding environmental and social/ethical aspects.

This article aims at developing an integrated multi-criteria decision model (MCDM) that supports recycling partner selection in the electrics and electronics industry and takes financial, environmental and social dimensions into account.

2 CONCEPT OF SUSTAINABLE SUPPLY CHAIN MANAGEMENT

SSCM is based on the adoption and extension of supply chain management concepts. According to Harland, supply chain management can be defined as "the management of a network of interconnected businesses involved in the ultimate provision of product and service packages required by end customers" (Harland, 1996). SSCM can be extended by the concept of sustainability, which encompasses social, environmental and economic aspects (Carter and Rogers, 2008). Shrivastava takes a more ecological rather than sociological view at sustainability, which he defines as "the potential for reducing long-term risks associated with resource depletion, fluctuations in energy costs, product liabilities, and pollution and waste management" (Shrivastava, 2007). In contrast, Sikdar takes a "macro-viewpoint" at sustainability that includes social, environmental and economic aspects. He calls sustainability "a wise balance among economic development, environmental stewardship, and social equity" (Sikdar, 2003).

In order to achieve a balance between environmental, social and economic dimensions (idea of the "triple bottom line" developed by Elkington, 2004) we decided to follow the definition of SSCM formulated by Carter and Rogers who describe it as the strategic achievement and integration of an organization's social, environmental, and economic goals through the systemic coordination of key inter-organizational business processes to improve the long-term economic performance of the individual company and its value network (Carter and Rogers, 2008).

Figure 1 illustrates the main components of SSCM, as well as the risks threatening it. The different dimensions of sustainability (environmental, economic and social performance of an organization) constitute three equally strong pillars that the building rests on, whereas risk and compliance management provide its foundation. The identification and mitigation of risks ensures long-term profitability. Laws, guidelines and standards serve as a basis for the implementation of SSCM throughout the supply chain.

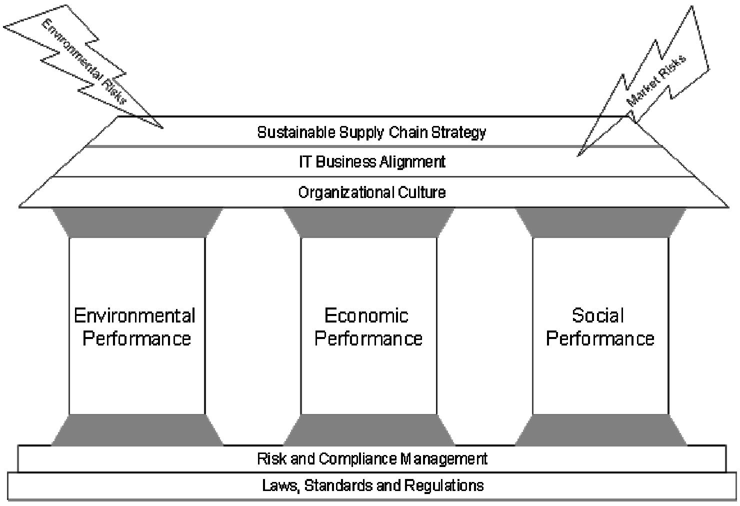

Fig. 1. House of SSCM (Wittstruck and Teuteberg 2010)

Apart from that, SSCM includes values and ethics that need to be established in organizations. The concept also requires an efficient, flexible and "green" IT environment and the integration of the long-term goal of sustainable development into the corporate strategy. If these aspects are effectively combined, they can successfully protect the network against market, environmental and social threats and risks (cf. Figure 1).

3 METHOD

The research method that this paper is based on can be characterized as design science research (Hevner et al., 2004) whereas the artefact developed in the following sections can be described as a holistic approach for sustainable partner selection in the electrics and electronics industry. The development of the model consists of the following phases:

3.1 Literature Review

A systematic literature review was conducted in order to determine the current state of research. The limitations of a systematic literature review lie in the paper selection process. However, we tried to minimize this risk by following a proven course of action for the creation of a literature review (Swanson, E.B., Ramiller, N.C. 1993, Webster and Watson 2002). The restriction of the source material to high-quality articles leads to reliable results about the state of the art in SSCM research.

The search and the selection of the literature were carried out as follows: a systematic analysis of eleven high-quality journals was conducted. The oldest articles that were included date back to the year 1997. Table 1 shows the selected journals and how they have been evaluated in renowned international rankings. It becomes obvious from the table that only high-quality journals have been taken into account.

The following key words were used in order to achieve comprehensive search results: supply chain logistics, sustainability, green decision, multi objective, Analytical Hierarchy Process, Analytical Network Process, AHP, ANP, Fuzzy Logic, Data Envelopment Analysis, Promethee, TOPSIS, Technique for Order Preference by Similarity to Ideal Solution, Operational Competitiveness Rating, OCRA, Stochastic Frontier Analysis, SFA, Free Disposable Hull, FDH, Cross Efficiency Analysis, Recycling, and Recycling Networks. The inclusion of many synonyms and/or semantically very similar expressions led to more exhaustive search results. Each identified article was checked for its relevance to the topic by reading the respective abstract and introduction. Subsequently, according to the framework of literature analysis the main approaches, criteria, trends and validation methods of partner selection were analyzed. To improve the quality of the analyses, both authors of this paper were involved in reviewing and coding the analyzed articles. The inter-rater reliability was good (inter-rater percentage agreement: > 92 % in all analyses).

Table 1. : Journal Selection (cf. Harzing 2009)

	Cranfield University School of Management 2010	British Association of Business Schools (ABS) Ranking 2010	Wirtschafts-universität Wien 2008	VHB Ranking 2008	Centre National de la Recherche Scientifique 2008	Australian Business Deans Council 2008	Aston University 2008	University of Queensland 2007	Erasmus Research Institute of Management Journals Listing 2006	WKWI 2008
Information Systems Research	4	4	A+	A+	1	A*	4	1	STAR	A
International Journal of Innovation and Sustainable Development	*N.R.*	*N.R.*	*N.R.*	C	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*
Int. Journal of Logistics Management	3	2	A	D	3	B	1	3	S	*N.R.*
Int. J. of Physical Distribution & Logistics Management	3	2	A	B	4	C	1	3	S	*N.R.*
International Journal of Production Research	3	3	A	B	2	A	4	3	P	*N.R.*
Journal of Business Logistics	3	2	*N.R.*	B	*N.R.*	B	2	3	S	*N.R.*

	Cranfield University School of Management 2010	British Association of Business Schools (ABS) Ranking 2010	Wirtschafts-universität Wien 2008	VHB Ranking 2008	Centre National de la Recherche Scientifique 2008	Australian Business Deans Council 2008	Aston University 2008	University of Queensland 2007	Erasmus Research Institute of Management Journals Listing 2006	WKWI 2008
Journal of Cleaner Production	*N.R.*	*N.R.*	*N.R.*	C	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*
Logistics Research	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*	*N.R.*
MIS Quarterly	4	4	A+	A	1	A*	4	1	STAR	A
Naval Research Logistics	*N.R.*	3	A	B	3	B	*N.R.*	*N.R.*	S	*N.R.*
SCM: An International Journal	3	3	*N.R.*	C	4	A	3	4	S	*N.R.*
Rank Interpretation *N.R.*: Not ranked	4: World leading 3: Top international	4: Top journal 3: Highly regarded journal 2: Well regarded journal	A+: Top A: World-wide distributed	A+: Highest A…D E: Lowest	1*: Highest quality 1-3: Intermediate 4: Lowest quality	A*: Leading A: Highly regarded B: Well regarded C: Recognized	4: World leading 3: Internationally excellent 2: Recognized internationally	1: Highest quality 2-4: Intermediate 4: Lowest Quality	STAR: Top P: Best S: Recognized academic reputation	A: Top

3.2 Partner Selection

Because recycling companies can be both supplier (providing recycled materials for production) and customer (by purchasing used electronic devices) the term “partner selection” is preferred in this analysis to other known terms, e.g. ‘supplier selection’ or ‘vendor ‘selection’ (Zarvić et al. 2010, Weber et al., 1991).

However, the selection of recycling partners focusing environmental, social and financial dimensions was not adequately tackled from the research community so far. In the section Development of a Partner Selection Method opportunities and limitations of these approaches regarding this topic are analyzed in order to develop an adequate holistic approach.

3.3 Identification of Partner Selection Criteria

First of all, existing partner selection criteria are identified on the basis of the systematic literature review. All criteria mentioned in the articles are extracted and tabulated. Table 3 also illustrates whether or not the criteria were validated in the research articles, and if yes, in what way.

3.4 Criteria Validation and Weighting

The criteria will be validated in the context of a survey among company representatives from recycling networks of the electrics and electronics industry. The experts will be asked whether the criteria mentioned in the literature seemed relevant to them. Also, they will be invited to name further criteria applied by their own or other companies. Subsequently, the participants will be asked to compare the criteria pairwise according to the AHP approach. A Fuzzy-AHP matrix will be generated on the basis of the participants' responses. Based on this matrix the criteria will be weighted by means of the software @Risk, resulting in an average relative weighting of the relevant criteria.

3.5 Design of the Study

The study is conducted by means of an online questionnaire and is carried out as follows:

Defining the Sample: Recycling networks of the German electrics and electronics industry will be selected to form the study sample. A special focus will be placed on products in the fields of entertainment electronics, telecommunication, computer hard-ware, medical technology or automotive IT. The reason for selecting these particular branches of production is that they cause particularly many ecological disturbances and, as a consequence, potential health problems. For example, some of the mentioned goods contain toxic substances and end up as e-waste on dumping grounds around the globe, e.g. in Asia or Africa, where they pollute the environment. Employees in production plants in China, Vietnam, Nigeria or India are not always sufficiently informed about the poisonous substances that they may be handling on a daily basis. Apart from these ecological considerations, the recycling of the above listed products (including disassembly, processing, separation, sorting of parts etc.) is almost as laborious as their production and causes the companies comparatively high costs (Walton et al., 1998). In view of these problem complexes it becomes clear that the electrics and electronics industry is of special interest for researchers on SSCM, since it constitutes the primary target group for SSCM solutions.

Pre-Test: In February 2011, the questionnaire will be tested for comprehensibility in a pre-test with 10 participating business representatives.

Implementations: Between February and March 2011, experts will be invited to participate in the survey. These experts were mainly identified by searching the internet (search on “Xing” and “Linkedin”). A total of 3000 personal invitations to participate will be posted. We calculate a return rate of 3 %.

Analysis and Interpretation: An analysis phase will follow between March and April 2011. During this phase, the data will be consolidated evaluated by using AHP-Fuzzy-TOPSIS.

3.6 Model Validation

Implementation and Analysis: The individual steps from the Fuzzy AHP matrix and the weighted vectors to the final partner selection decision (by means of TOPSIS) are implemented in @Risk in order to test to what extent the model can be integrated into available standard software. For the selection of a recycling partner by means of the TOPSIS method, the data of ten electronic waste recycling companies will be stored in @Risk. The implementation of the model in @Risk is a first step to verify the usefulness of the approach for business practice. All data relevant for the evaluation of the criteria shall be retrieved by analyzing the recycling companies' websites.

Experiments: Experiments will be conducted in order to check whether the model influences the participants' decision making regarding sustainable partner selection.

4 RESULTS FROM THE LITERATURE

At this point in time we have completed the third phase of our approach. The results gained on the basis of the systematic literature review are presented in the following section. In particular, the findings provide new insights regarding an adequate method for sustainable partner selection and relevant selection criteria.

4.1 Development of a Partner Selection Method

Important approaches for partner selection are summarized in Table 3. For our analysis, the following criteria were of particular interest:

- Approach: Which method was used?
- Focus on Sustainability: Does the article focus on financial, social and environmental issues?
- Industry Focus: What are the main results and topics?
- SCOR-Process: Which of the SCOR (Supply Chain Operations Reference Model) processes are considered?
- Purpose: What is the main objective?
- Findings: What are the findings?
- Major Limitations: What are major limitations?

Table 2. Partner Selection Approaches

Approach	Authors, Year	Focus on Sustai-nability	Industry Focus	SCOR-Process	Purpose	Findings	Major limitations
AHP	Sarmiento, R.; Thomas, A. (2010)	GreenSCM	No	Make	• The purpose of this paper is to discuss research gaps and the potential applications of analytic hierarchy process (AHP) in an internal benchmarking process used to identify improvement areas when firms attempt to adopt green initiatives with a supply chain perspective.	•The application of AHP to study the various themes mentioned above is not new. Nevertheless, no previous investigation has identified the limitations in those studies. Furthermore, previous paper has not proposed a multitier AHP approach to analyze the problems firms taking part in a supply chain might encounter when implementing green initiatives.	•The interrelationship among criteria and the uncertainty of human decision making are not considered. •AHP supports a weighting of criteria/factors but gives only few hints how to find the supplier which meets these criteria best.
	Liu, L.; Berger, P.; Zeng, A.; Gerstenfeld, A. (2008)	No	No	No	• The purpose of this paper is to show that there is a wealth of academic literature that qualitatively examines the outsourcing and offshoring from a go/no go perspective. The paper examines the complex "where to outsource" question by applying a	•The location selection decision is a component of the outsource supplier selection decision. •The AHP model effectively manages the complexity of the decision making process, incorporating all decision criteria harmoniously. •A method such as AHP, which is able to incorporate both qualitative and quantitative criteria	

Approach	Authors, Year	Focus on Sustai-nability	Industry Focus	SCOR-Process	Purpose	Findings	Major limitations
					quantitative approach called Analytic Hierarchy Process (AHP).	into evaluations, would streamline the decision-making process. •The AHP process allows firms to look at a portfolio of choices and determine which firms are basically equal in qualifications.	
	Gaudenzi, B.; Borghesi,A. (2006)	No	No	Plan	•The aim of the research is to provide a method to evaluate supply chain risks that stand in the way of the supply chain objectives.	•The appreciation of the most critical supply chain risks comes from evaluations of the impacts and a consideration of the cause-effect relationships. The involvement of key managers is essential. In the case study the two most divergent evaluations were from the logistics manager and the sales manager.	
	Kahraman, C.; Cebeci, U.; Ulukan, Z. (2003)	No	White good manufacturer	Make	•The aim of this paper is to use fuzzy analytic hierarchy process (AHP) to select the best supplier firm providing the most satisfaction for the criteria determined.	•The purchasing managers of a white good manufacturer established in Turkey were interviewed and the most important criteria taken into account by the managers while they were selecting their supplier firms were	

Approach	Authors, Year	Focus on Sustai-nability	Industry Focus	SCOR-Process	Purpose	Findings	Major limitations
						determined by a questionnaire. The fuzzy AHP was used to compare these supplier firms.	
Fuzzy and AHP	Bottani, E.; Rizzi, A. (2005)	No	E-Procurement	Source	•The paper addresses the issues of how supplier selection criteria can be usefully adopted in real case applications to ponder and rank viable candidates.	•The hierarchy covers relevant issues related to e-procurement deployment •The framework seems adequate, since advanced MADM methods can be applied easily in order to rank potential candidates in terms of the “electronic transaction” criterion.	•The interrelationships among criteria are not considered. •AHP supports a weighting of criteria/factors but gives only few hints how to find the supplier which meets these criteria best.
	Haq, A.N,; Kanaan, G. (2006)	No	Manu-facturing Company	Source	•This paper presents an integrated approach for supplier selection. •The approach is validated by a case study performed in an original equipment manufacturing company located in Southern India.	•A fuzzy analytical hierarchy process (FAHP) and genetic algorithms (GA) are presented and validated. •The approach supports decision making in built-to-order (BTO) supply chain environments.	
	Lu, L.Y.Y.; Wu, C.H.; Kuo, T.C. (2007)	GreenSCM	No	Source	•Developing a MODM-process for GreenSCM to help SC manager in measuring and evaluating	•This study presents a AHP and Fuzzy approach to enable managers to evaluate various projects and establish an	

Approach	Authors, Year	Focus on Sustai-nability	Industry Focus	SCOR-Process	Purpose	Findings	Major limitations
					suppliers' performance based on AHP decision-making method. •To reduce subjective bias in designing a weighting system, a fuzzy logic process is used to modify the AHP.	environmentally benign product design.	
AHP, TOPSIS	Perçin, S. (2009)	No	No	Deliver	•The purpose of this paper is to provide a good insight into the use of a-two-phase AHP and TOPSIS approach that is a multi-criteria decision-making methodology in the evaluation of 3PL providers.	•This model provides decision makers with a simple, flexible, and easy-to-use approach to evaluate potential 3PL providers efficiently. Findings demonstrate that the proposed benchmarking framework, with minor modifications, can be useful to all firms in their 3PL provider selection decisions.	•The interrelationship among criteria and the uncertainty of human decision making are not considered.
ANP	Bayazit, O. (2006)	No	No	Source	•The purpose of this paper is to provide a good insight into the use of analytic network process (ANP) in evaluating supplier selection problems.	•It is shown that ANP can be used as a decision analysis tool to solve multi-criteria supplier selection problems that contain interdependencies. •ANP is a complex methodology and requires more comparisons than the traditional AHP and	•The uncertainty of human being decision making is not considered. •It is very time-consuming to use this complex approach in business practice.

Approach	Authors, Year	Focus on Sustai-nability	Industry Focus	SCOR-Process	Purpose	Findings	Major limitations
						it increases the effort.	
	Kirytopoulos, K.; Leopoulos, V.; Mavrotas, G.; Voulgaridou, D. (2010)	No	No	Source	•The purpose of this paper is to provide a meta-model for supplier evaluation and order quantity allocation, based on a MCDM method, namely the Analytic Network Process (ANP) and a multiobjective mathematical programming method (MOMP), the AUGMECON.	•The proposed meta-model constitutes an efficient method that enables managers to actively participate in the decision making process and exploit the “qualitative value” of their suppliers, while minimizing the costs and the mean delivery times. In addition, it is proved to be suitable for the enterprise clusters, as it adapts a multiple sourcing strategy and enhances the partnership among the members.	
	Zhu, Q.; Dou, Y.; Sarkis, J.(2010)	Environ-nmental	No	Source	•The purpose of this paper is to present the development of a methodology to evaluate suppliers using portfolio analysis based on the analytical network process (ANP) and environmental factors.	•The technique is useful and versatile. The paper clearly discerns various characteristics of the suppliers and produced recommendations on supplier management for an exemplary case scenario.	
	Sarkis, J. (1998)	Environ-mental	No	No	•This paper integrates these elements and their attributes into a strategic	•The ANP technique, which has been sparingly investigated by researchers or	

Approach	Authors, Year	Focus on Sustai-nability	Industry Focus	SCOR-Process	Purpose	Findings	Major limitations
					assessment and decision tool using the systems with feedback or analytical network process (ANP) technique first introduced by Saaty.	applied by practitioners, is useful for modeling dynamic strategies systemic influences on managerial decisions.	
	Ustun, O.; Demirtas, E.A. (2008)	No	Plastic Molding Firms	Source	•The purpose of this paper is to choose the best suppliers. •Defining the optimum quantities among selected suppliers to maximize the total value of purchasing (TVP), and to minimize the total cost and total defect rate.	•The quality of final solutions obtained by ϵ-constraint, preemptive goal programming (PGP) and reservation level driven Tchebycheff procedure (RLTP) methods is compared by using an additive utility function. RLTP is better than the others according. •It is also possible to adapt this multi-period MOMILP model to multi-product case. This integrated approach can be improved to reflect decision maker’s preferences with more accuracy.	

Approach	**Authors, Year**	**Focus on Sustai-nability**	**Industry Focus**	**SCOR-Process**	**Purpose**	**Findings**	**Major limitations**
Fuzzy and DEA; Fuzzy and AHP	Kuoa, R. J.; Leeb, L. Y.; Huc, T.L. (2008)	No	Automotive	Source	•This study intends to develop a novel performance evaluation method, which integrates both fuzzy analytical hierarchy process (AHP) method and fuzzy data envelopment analysis (DEA) for assisting organizations to make the supplier selection decision.	•A Case study on an internationally well-known auto lighting OEM company shows that the proposed method is very suitable for practical applications.	•The interrelationship among criteria and the uncertainty of human decision making are not considered.

Former research in the field of partner selection focused primarily on the “pre-stage” of the actual supply chain, that is, on direct suppliers (Ustun, O.; Demirtas, E.A., 2008); Kuoa, R. J.; Leeb, L. Y.; Huc, T.L., 2008); Kirytopoulos, K.; Leopoulos, V.; Mavrotas, G.; Voulgaridou, D., 2010). For the selection of recycling partners, however, this approach is insufficient because recycling companies can come into play both as a supplier and as a costumer the pre and post stage of the supply chain. For example, recycling companies can act as suppliers of recycled materials for the production of new goods or as buyers of electronic and other waste. Existing research works often focus on criteria like cost, time and quality (Zhu, Q.; Dou, Y.; Sarkis, J., 2010; Sarkis, J., 1998). Some authors also take environmental factors into account when discussing the issue of partner selection (Su, Y.; Jin, Z.; Yang, L., 2010; Sarkis, J., 1998; Sarmiento, R.; Thomas, A., 2010). However, a comprehensive view that integrates environmental, social and financial factors has been missing to date. Our study aims at filling this research gap.

Our Approach: Different methods for the weighting of criteria are suggested in the literature, the most popular ones being cost-utility analysis, quality function development and the AHP approach (Keeney, R.L.; Raiffa, H., 1993). Whereas quality function development is especially applied for the development of products and services, cost utility analysis has the disadvantage of not including the pairwise comparison of criteria. Instead, it is merely checked that the addition of all weighting factors does not result in a percentage higher than 100%. Therefore, in this paper the AHP approach is used as a basis for the recording and weighting of the criteria. The

Analytic Hierarchy Process makes it possible to create a hierarchical structure for a multicriterial decision problem and to aggregate it at the different levels, but on the other hand it neglects the uncertainty and imprecision of human thought. The Fuzzy Set Theory is applied to overcome this limitation, for fuzzy logic can be used to describe fuzzy quantities. Hence, a combination of both approaches seems promising. Subsequently, the TOPSIS method can be applied to find out which alternatives best fulfill the identified criteria; i.e. TOPSIS is used to compare and rank recycling partners and their criteria values. This happens by means of a relative efficiency analysis in which two virtual alternatives are defined: the overall best and the overall worst one. The characteristics of the potential partners need to be compared to these alternatives (Mahmoodzadeh et. al. 2010).

In summary, this article differs from similar works in several ways: an integrated Fuzzy-AHP-TOPSIS approach is taken, all dimensions of sustainability are considered for the selection of partners, the criteria are systematically derived and empirically validated, the focus is on recycling networks of the electrics and electronics industry and the model is evaluated on the basis of an exemplary implementation and experiments.

4.2 Partner Selection Criteria

In the context of our literature review we identified 35 articles in which partner selection criteria were analyzed. Table 4 provides an overview of these criteria. The number of proposed criteria per publication varies between 4 and 18, with an average number of 9 criteria. The criteria were mostly derived from literature and not always validated by experts from professional practice. It becomes immediately obvious that quality and delivery criteria are by far the most frequently proposed ones. Out of these, process quality (23 occurrences), delivery time (22 occurrences) and product quality (19 occurrences) (Webber et al., 1991; Bos-Brouwers, 2010; Choy, Lee, 2003) received the most mentions. Financial criteria like price (18 occurrences) and financial capability (12 occurrences) were also very frequently mentioned (Ordoobadi, 2009; Kwong et al., 2000; Chan et al., 2008). IT and risk criteria received a medium number of mentions (Petroni, A. et al., 2000; Sarkis, J. et al., 2002) whereas social and environmental criteria were only rarely referred to. The know-how and the working conditions of the employees were mentioned as social criteria. Repeatedly suggested environmental criteria were the use of environmental management systems (EMAS) and the type of product packaging (Sarkis, J. et al. (2002); Simpson, M.P. et al. 2002).

In view of all this, which criteria seem to be the most significant ones for the selection of recycling partners? According to the triple bottom line concept, the criteria should cover financial, environmental and social factors. Also, we want to account for the special characteristics of recycling companies. In accordance with the authors of the analyzed articles (as e. g. Ordoobadi, 2009; Kwong et al., 2000; Chan et al., 2008) we define price and financial capabilities as important criteria. In the context of this study, a recycling company’s financial capability is regarded as a critical factor for its long-term capability to survive. In turn, the recycler’s long-term survival is of high significance because electronic products often have a lifespan of several years, which means that cooperative relationships in the field of recycling must necessarily be long-term. Hence, we suggest the following selection critiera:

- Price
- Financial Capability

The main purpose of cooperating with a recycling company is to ensure the proper disposal of production materials and electronic waste. If required, the recycling company should be capable of recycling or disposing of large quantities of material and complex products (Dogan et al., 2003; Sun, et al., 2009). Hence, we suggest the following selection critiera:

- Recycling Capability
- Quality of Recycling Processes

Also, compliance with laws, guidelines and standards regarding the recycling and disposal of waste (WEEE, EuroStar etc.) constitutes a particular challenge for recycling companies because all these directives have a direct impact on their core business. Environmental Management Systems support the holistic management of environmental laws, guidelines and standards (Simpson et al., 2002; Kannan, et al., 2002). Thus, we suggest another selection criterion:

- Effective Implementation of Environmental Management Systems

Some of our electronic waste ends up at dumping grounds in Africa or in the Far East where health and safety measures are far less strict. If an international recycling company succeeds in communicating that it adheres to equally high safety standards for employees handling electronic waste at each of its locations, this can be a decisive competitive advantage (Bos-Brouwers, 2010). This correlation can be captured by means of the following criteria:

- Standardized Health and Safety Conditions
- Sustainable Image

It must also be pointed out that recycling partners only receive their raw materials after they have been used by the customer. This temporal delay results in the need for especially careful coordination and planning way before the actual utilization of the recycling service. The producer and the recycler need to exchange particularly detailed information regarding the exact composition of the product to be recycled. Such an exchange of information enables recyclers to prepare for the specific recycling methods that new products may require. It is therefore very important to provide configurable IT interfaces that enable the exchange of information (Chan et al., 2008; Sridhar, 2010). As a result, we define another selection criterion:

- Efficient IT-Interfaces

Furthermore, recycling companies are often positioned at a pre-stage of the supply chain. They provide processed materials for further production and also act as consultants to producers regarding sustainable production methods and eco-friendly product composition (Ordoobadi, 2009; Sridhar, 2010; Bevilacqua, Petroni, 2002). Therefore, we add the following criterion to our catalogue:

- Know-how in Electronic Materials and Manufacturing Processes

All in all, we have suggested nine criteria, which correspond to the average number of criteria mentioned in related research articles. In business practice, these criteria could be used as a starting point for the solution of sustainable partner selection problems.

Table 3. Review on Partner Selection Criteria

Main Criteria	Sub-Criteria	Sum of mentioned criteria	Author	Lu et al. (2007)	Bayazit (2006)	Ustun et al. (2008)	Kang et al. (2010)	Wittstruck, Teuteberg (2011)	Dickson (1966)	Weber et al. (1991)	Bos-Brouwers (2010)	Choy, Lee (2003)	Zhu et al. (2010)	Ting, Cho (2008)	Ordoobadi (2009)	Kwong et al. (2001)	Chan et al. (2008)	Sridhar (2010)	Bevilacqua, Petroni (2002)	Bottani, Rizzi (2006)	Towers, Song (2010)	Akarte et al. (2001)	Jain, V. et al. (2004)	Li, S. et al. (2002)	Craig, M. et al. (1997)	Walton, S.V. et al. 1998	Vonderembse, M. (1999)	Petroni, A. et al. (2000)	Sarkis, J. et al. (2002)	Simpson, M.P. et al. (2002)	Kannan, V.R. et al. (2002)	Muralidharan, C. (2002)	Sharland, A. (2001)	Kim, J.Y. et al. (2010)	Dogan, I., Sahin, U. (2003)	Sun, S.Y. et al. (2009)	Chan, Chan (2004)
			Domain	Supplier Selection	Vendor Selection	Supplier Selection	Supplier Selection	Recycling Networks	Vendor Selection	Supplier Selection	SMEs	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Producer Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supplier Selection	Supply Chain Partner	Supplier Selection	Supplier Selection	Supplier Selection
			Number of proposed Criteria	5	8	4	4	5	11	10	12	9	10	11	10	7	18	16	9	6	19	9	6	5	7	10	4	6	21	15	8	12	5	5	5	10	5
			Validation of Criteria	300 Companies	Fo	Interviews	8 Experts from universities and companies	117 Companies of Electronic Industry	Literature Review	Literature Review; 74 research articles	Semi-structured interviews	Literature Review	Literature Review	Literature Review	Literature Review	Literature Review	Literature Review	Literature Review	Literature Review	Literature Review	Literature Review	Literature Review	Literature Review	Empirical Study	Literature Review	10 Experts	Empirical Study	Empirical Study	Literature Review	Exploratory Study	Empirical Study	Literature Review	Empirical Study	Literature Review	Literature Review	Empirical Study	Literature Review and Interviews
Social	Working Conditions/ Culture	6						1	1		1		1						1										1								
	Job Satisfaction	1									1																										
	Workplace Safety	1									1																										
	Code of Conduct	1									1																										
	Stake-holder Communi-cation	2									1																		1								
	Health and Safety Standards	1									1																										
	Education/ Know-how	6							1			1			1			1												1			1				
Environmental	Materials Used	5		1				1			1		1													1											
	Energy Con-sumption	4		1							1		1													1											
	Solid residues	3		1									1													1											
	Liquid residues	3		1									1													1											
	Recycling processes	2									1															1											
	Gaseous	3		1							1															1											
	Residues	1																								1											
	Environm. Mgmt Systems and Certific.	5											1									1				1				1	1						
	Green	2						1																		1											
	Geogra-phical Location	7							1	1								1	1	1	1									1							
	Packaging ability	5							1	1	1															1				1							

Financial	Price	18			1				1	1		1	1	1		1	1	1					1	1				1	1	1		1	1		1	1	
	Top Mgmt. Capability	11			1				1	1		1					1			1									1	1				1			
	Manu-facturing Capabilities	12										1				1		1		1		1	1	1					1	1		1	1	1			
	Personnel Capabilities	3			1													1														1					
	Financial Capability	12			1				1					1	1	1	1	1	1	1										1		1	1				
	Market Share	3			1												1													1							
Risks	Customer Complaints	3				1																							1					1			
	Process Assurance	5										1			1						1									1	1						
	Political Stability and Exchange Rates	2															1	1																			
	Delivery Delay	10												1	1		1				1	1			1		1		1	1					1		
	Warranties	6								1				1	1			1			1								1								
Delivery/Quality	Product Innovation	9								1											1	1	1				1		1	1						1	1
	Product Quality	19					1		1	1				1		1	1	1	1		1	1	1				1	1	1		1	1			1	1	
	Process Quality	23					1			1	1	1	1	1	1	1	1	1	1		1	1	1		1			1	1		1	1			1	1	1
	Process Innovation and Flexibility	16			1	1						1	1		1		1	1	1		1			1	1				1		1	1				1	1
	Process Capability	7			1	1		1	1								1				1								1								
	Geometric Capability	1																				1															
	Customer Service / Respon-siveness	17										1		1	1	1	1	1	1		1			1	1				1	1	1	1		1		1	
	Delivery Time	22			1	1				1		1		1		1	1	1			1	1	1	1			1	1	1	1	1	1	1		1	1	1
	General Image	2							1									1																			
IT/IS Infrastructure	IT, Interfaces, Commu-nication Systems	10					1	1									1	1		1					1				1		1	1				1	
	Software	3																				1							1							1	
	IT - Capability	15							1	1			1				1	1	1	1					1			1	1	1		1		1		1	
Costs	Economies of Scale	4					1							1	1																						
	Delivery Costs	6												1			1				1								1			1					
	Production Costs	5												1			1				1								1								
	Cost structure	8													1		1		1		1				1				1								1

5 AN EXEMPLARY CASE STUDY

At the current phase of our research project we are preparing an empirical study in order to validate our approach. However, we will illustrate our approach by means of an exemplary case study based on fictive data. We assume a decision maker who wants to evaluate three recycling partners by means of the Fuzzy-AHP-TOPSIS approach. The procedure can be summarized as follows (Saaty, 1980; Mahmoodzadeh et al., 2007):

1. Formulating hierarchy: The hierarchy is structured into different levels: the goal, the criteria and the alternatives level. The goal of our study is to select the most adequate partner. On the criteria level we model the selection criteria presented in the chapter on Partner Selection Criteria. Finally, on the alternatives level we model three alternative recycling companies. The hierarchy of our case study is presented in Figure 2.

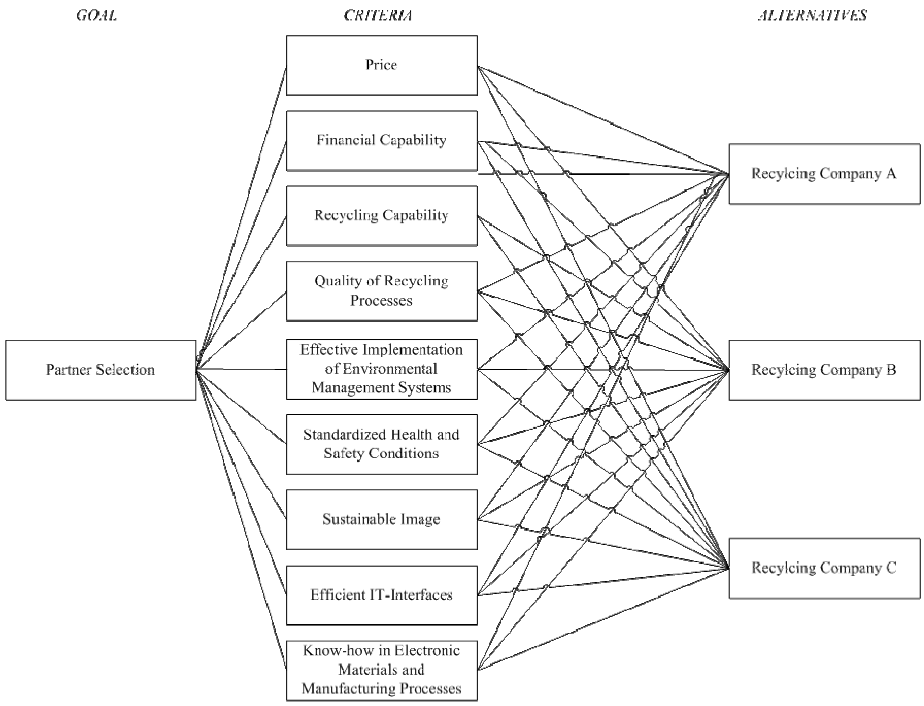

Fig. 2. Decision Hierarchy

2. Modeling Fuzzy Importance: A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function, which assigns a grade of membership to each object that ranges between zero and one (Mahmoodzadeh et al., 2007). A triangular fuzzy number obtains three parameters that characterize the smallest possible value, the most promising value and the largest possible value. Table 4 provides an overview of the linguistic scale and the triangular fuzzy numbers assumed in this case study.

Table 4. Linguistic Scale

Linguistic Scale	Triangular Fuzzy Number
Absolutely more important	(5/2,3,7/2)
Very strongly more important	(2,5/2,3)
Strongly more important	(3/2,2,5/2)
Weakly more important	(1,3/2,2)
Equally important	(1/2,1,3/2)
Just equal	(1,1,1)

Figure 3 shows a Triangular Fuzzy Function μ(p). For instance, the linguistic scale “strongly more important” is determined by p1= 3/2, p2=2 and p3=5/2.

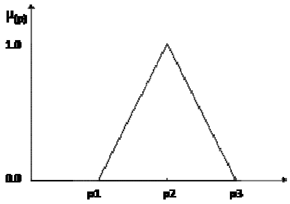

Fig. 3. Triangular Fuzzy Function

3. Creating an Evaluation Matrix: AHP uses pairwise comparisons to weight and rate the criteria. In our example the decision maker compares nine criteria with each other. Table 6 shows the exemplary evaluation matrix.

Table 5. Evaluation Matrix

	Price	Fin. Capa-bility	Recycling Capability	Quality of Recycling Processes	Effective Impl. of EMIS	Standar-dized H&SC	Sustainable Image	Eff. IT Interfaces	EMMP Know-how
Price	1	(1,3/2,2)	(1/2,2/5,1/3)	(1,3/2,2)	(1,3/2,2)	(1/2,1,3/2)	(1/2,1,3/2)	(3/2,2,5/2)	(1,3/2,2)
Financial Capability		1	(1,2/3,1/2)	(1/2,2/5,1/3)	(1,3/2,2)	(1,3/2,2)	(2,5/2,3)	(1/2,1,3/2)	(1,3/2,2)
Recycling Capability			1	(1/2,2/5,1/3)	(2,5/2,3)	(1,3/2,2)	(1,3/2,2)	(2,5/2,3)	(1,3/2,2)
Quality of Recycling Processes				1	(5/2,3,7/2)	(2,5/2,3)	(5/2,3,7/2)	(1/2,1,3/2)	(1/2,2/5,1/3)
Effective Imple-mentation of EMS					1	(1,3/2,2)	(1/2,1,3/2)	(1,3/2,2)	(1/2,1,3/2)
Standar-dized H&SC						(1,2/3,1/2)	(5/2,3,7/2)	(1,3/2,2)	(3/2,2,5/2)
Sustainable Image							1	(2,5/2,3)	(1/2,1,3/2)
Efficient IT Interfaces								1	(2,5/2,3)
Know-how in EMMP									1

4. Calculating Normalized Weighting Factors: The normalized weighting factor reflects the relative importance of the partner selection criteria. It can be concluded from the following normalized weighting factor W that “price” (0.21) is the most important selection criterion, followed by “quality of recycling processes” (0.13) and “efficient IT interfaces” (0.12):

   W = {0.21, 0.13, 0.08, 0.07, 0.17, 0.14, 0.02, 0.12, 0.05}

5. Evaluating Alternatives: The TOPSIS approach is used to identify the optimal partner. To this end, after having calculated the normalized decision matrix, the weighted normalized decision matrix is calculated by multiplying the normalized decision matrix by its associated weights. Subsequently, the separation measures are calculated using the Euclidean distance (Mahmoodzadeh et al., 2007). Finally, the relative closeness to the ideal solution is calculated and a ranking of the three alternative companies is derived. As you can see from Table 6 Recycling Company B achieves the best score.

Table 6. Final Ranking of Recycling Partner

Partner	Score
Recycling Company A	0.2156
Recycling Company B	0.7321
Recycling Company C	0.0103

6 CONCLUSION

6.1 Implications

Due to the increasing number of electric devices being produced, the recycling of these materials will become more and more important. Thus, the selection of recycling partners with a view to environmental and social issues will become a significant topic for supply chain managers. The approach proposed in this paper considers the complexity of the supplier selection problem and includes financial, environmental and social dimensions. The model is intuitive and can be easily computerized. The results indicate that the Fuzzy-AHP-TOPSIS approach can be used as a decision making instrument for supply chain managers who need to select recycling partners. Both tangible and intangible factors can be incorporated into the model. In addition, assessment bias in pairwise comparison is reduced by combining AHP with fuzzy logic.

However, there are limitations to the approach. For instance, interrelationships among factors are not considered. If there are feedbacks and interdependencies among the factors, an unimportant factor may turn out to be far more important than even the most important one. The interdependencies that play a role in real-life partner selection problems are not captured in our study. Furthermore, the so-called Rank Reversal Problem has been pointed out by critics (Macharis et al., 2004). The term denotes that a ranking which is based on a comprehensive evaluation can be completely reversed by adding another alternative. For example, if criterion A is ranked higher than criterion B, the addition of a third criterion C might change the ranking to C>B>A. It is disputable whether there is an inherent logic to this phenomenon.

6.2 Further Research

Several research questions are still open at this stage: What do decision makers think of the suggested criteria? Will they consider them relevant? In what way does the holistic approach influence the decision making process?

These questions are will be part of our further research. As a next step we will verify the proposed criteria by interviewing experts from business practice. To this end an online questionnaire will be created. Subsequently, the approach will be implemented in @Risk in order to provide a software tool for sustainable partner selection. The instrument will then be tested by means of experiments which will also serve to investigate to what degree the approach influences the participants' decisions regarding sustainable partner selection. All these steps are currently in preparation.

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AUTHOR BIOGRAPHIES

David Wittstruck is an external research associate at the Chair in Accounting and Information Systems led by Prof. Frank Teuteberg. His research interests lie in the realm of Sustainable Supply Chain Management and Supply Chain Performance Management. Since 2008 David Wittstruck has been working as a consultant at the Advisory Services Department of Ernst&Young GmbH in Düsseldorf.

Since 2007 **Prof. Dr. Frank Teuteberg** has been head of the subject area „Accounting and Information Systems“, which is part of the Institute of Information Management and Corporate Governance at the University of Osnabrueck. Prof. Teuteberg is founder of the innovation network ertemis (www.ertemis.eu) which is supported by the European Fund for Regional Development (EFRE) and the State of Lower Saxony. His main research interests are Corporate Environmental Management Information Systems, Sustainable Supply Chain Management, Cloud Computing, Green Logistics and IT Risk Management.