Development and Simulation of a Balanced Scorecard for Sustainable Supply Chain Management – A System Dynamics Approach

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ABSTRACT

The objective of this article is to develop a Balanced Scorecard (BSC) for Sustainable Supply Chain Management (SSCM). The BSC provides a framework for simulation experiments which serve to evaluate benefits of sustainability investments for the partners within a recycling supply chain. A system dynamics approach was employed to perform the simulation experiments. First, the simulations help to identify the preconditions that must be met before environmental and social measures can lead to a long-term profit increase for all network partners. Second, they demonstrate how limitations of the traditional BSC can be overcome, especially regarding multi-causal relationships between key performance indicators. The model is based on the results of a literature review and information gathered in expert interviews. The limits of the analysis lie in the fact that the simulation experiments are partly based on hypothetical assumptions. However, where possible, the authors have drawn on expert knowledge and existing surveys.

Keywords

Sustainable Supply Chain Management, Balanced Scorecard, System Dynamics, Simulation, Rebound Effect, Recycling Network.

1. INTRODUCTION

In recent years, the topic of Sustainable Supply Chain Management (SSCM) has received growing attention and has become an increasingly popular research area. Today, companies must tackle multiple new challenges: they have to address the problem of rapid climate changes, face the negative impact of the financial crisis and volatile oil prices, deal with the growing public interest in ecology (e.g. Green Logistics, Green Computing), and ensure environmental sustainability and energy efficiency. Immense pressure is also exerted by environmental legislation (e.g. EU law) as well as by the mass media and society as a whole, considering the consumers' growing demand for transparency and their increasing awareness of the conditions under which products are manufactured and distributed (as, for example, issues of environment, safety, and human rights). Adequate methods, technologies, information and communication systems are therefore indispensable for a management of recycling supply chains that aims at a balance between environmental and social goals and long-term profitability. Sustainable Supply Chain Management (SSCM) extends the traditional concept of Supply Chain Management by including environmental and social/ethical aspects in response to the general call for a more sustainable economy ([7], [38]).

The aim of this paper is to develop a Balanced Scorecard (BSC) for SSCM and to enhance it with methods of system dynamics. The BSC is used as a framework for simulation experiments that are conducted to evaluate the economic and environmental benefits of sustainability investments from the perspective of an exemplary recycling supply chain. Subsequently, we examine in how far the enhanced BSC overcomes the limitations of a traditional BSC with regard to SSCM.

2. THE CONCEPT OF SUSTAINABLE SUPPLY CHAIN MANAGEMENT

This paper follows Carter and Rogers who define Sustainable Supply Chain Management (SSCM) 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 ([7], p. 368).

Figure 1 illustrates the problem area and the scope of SSCM ("House of Sustainable Supply Chain Management"). The house is built on the triple-bottom line ([7], p. 369, [10]). The three dimensions of sustainability are visualized as the pillars which keep the building in balance. Risk and compliance management forms the building's foundation. In order to achieve long-term profits, risks have to be identified and mitigated. Laws, guidelines and standards serve as a starting point for the implementation of sustainability principles and practices along the supply chain.

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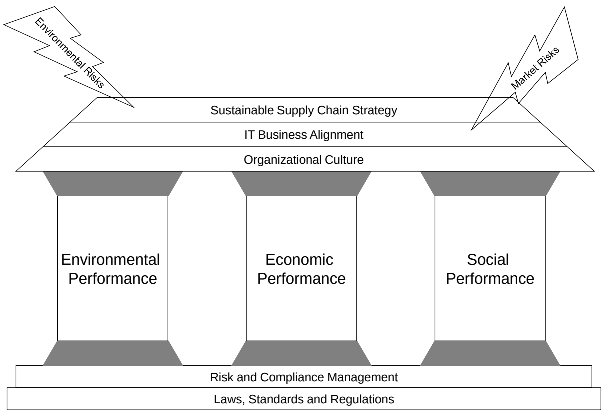

Figure 1: House of SSCM (c.f. [39])

In addition, SSCM requires the establishment of values and ethics throughout the organization, an efficient, flexible and "green" IT environment as well as the alignment of the corporate strategy to sustainable development. If these measures are taken, they effectively protect the supply chain against environmental and social threats and risks.

3. PRIOR RESEARCH

Table 1 briefly summarizes the core contents of some related publications dealing with performance measurement in (sustainable) supply chains. For our analysis, the following criteria were of particular interest:

1. *Simulation experiments*: Are simulation experiments used to evaluate the profitability of value networks?
2. *Sustainability*: Are environmental and social aspects considered at all, or does the focus lie on financial parameters only?
3. *Supply Chain*: Does the analysis refer to several partners of a supply chain?
4. *Performance Measurement*: Do the authors use a key performance indicator system, and if yes, which one?
5. *Scope/Purpose*: Which research questions or problems are dealt with in the article? What goal do the authors pursue?
6. *Findings*: What central research results are presented?

Table 1 shows that there is published research on simulation experiments in the fields of Performance Measurement and Supply Chain Management. Contributions presenting an approach for the financial evaluation of environmental and social investments in supply chains are missing. On the one hand, it seems reasonable to use the BSC as a framework for evaluations of sustainability investments because the BSC emphasizes the importance of non-financial measures for financial success ([5]). On the other hand, some authors have criticized that the Balanced Scorecard is a "static", not a "dynamic" instrument because time is not considered in it [36]. Particularly regarding SSCM, a static view seems questionable. Investments in sustainability often lead to high initial costs before generating higher profits at a later stage, e. g. through enhanced customer loyalty. Therefore, Georgiadis et. al 2008 and Hervani et al. 2005 ([13], [17]) point out that simulation experiments could be an adequate method for understanding the time-dependent cause and effect relationships between non-financial and financial indicators. They argue that by designing simulation experiments, decision makers are forced to estimate and quantify when environmental and social investments pay off. For instance, decision makers have to evaluate if and in which period an environmental image leads to higher customer satisfaction and higher profits ([13], [17]). In response to these arguments, we aim at developing a dynamic Balanced Scorecard for SSCM.

4. METHOD

The research method that this paper is based on can be characterized as design science research (cf. [18]), whereas the IT artifact developed in the following sections can be described as a simulation model for SSCM within the BSC framework. The simulation and development process encompassed the following phases:

1. *Literature Review*: We built on a systematic review of research literature on SSCM dating from between 1995 and 2010. 142 contributions from the following top journals were analyzed: "Management Information Systems Quarterly", "Journal of Business Engineering", "Ecological Economics", "Journal of Risk" and "Journal of Risk and Uncertainty", "International Journal of Physical Distribution & Logistics Management", "Naval Research Logistics", "Journal of Supply Chain Management" (cf. [35]).
2. *Balanced Scorecard:* Based on the literature review, an exemplary Balanced Scorecard for SSCM was designed.
3. *Simulation model:* The designed Balanced Scorecard was enhanced by a system dynamics simulation model.
4. *Expert interviews:* Between April and July 2010, experts from three companies were interviewed to improve the model's practical applicability. The experts were especially asked to test assumptions and to assess interdependencies between the KPIs. In this way, the model was gradually modified, refined and validated. The participating experts were selected according to their roles within the supply chain, each one representing one typical role. To ensure anonymity, the names of the companies were changed. The main characteristics of the companies are provided in Table 2.

Table 1: Prior Research

Authors, Year	Simulation Experiment	Sustain-ability	Supply Chain	Performance Measurement	Purpose	Findings
Brewer, P. C.; Speh, T.W. (2000): [5]	NO	NO	YES	YES (BSC)	• To identify key performance indicators for supply chain performance measurement.	• A modified balanced scorecard for SCM and examples of possible measures.
Noerreklit, H. 2000: [28]	NO	NO	NO	YES (BSC)	• To analyze the assumptions of the balanced scorecard.	• A significant weakness of the BSC is that "time" is not considered although "time" is an important dimension for Performance Management.
Maxwell, D.; van der Vorst, R. (2003): [26]	NO	YES	YES	NO	• To develop a method for effective sustainable product or service development (SD).	• A framework for implementing sustainable product and service development (SPSD) throughout the entire lifecycle of a product or service.
Hervani, A.A.; Helms, M, M.; Sarkis, J. (2005): [17]	NO	YES (Environ-mental Issues)	YES	YES (BSC)	• To introduce and provide an overview of the various issues related to environmental (green) supply chain management.	• Provides an integrative framework for study, design and evaluation of green supply chain management performance tools. The findings also identify a number of issues that need to still be addressed.
Matos, Stelvia; Hall, J. (2007): [25]	NO	YES	YES	NO	• To discuss the problems of integrating sustainable development concerns in the supply chain.	• A framework for SSCM and implications for practitioners and management theory.
Vlachos,D.; Georgiadis, P.; Iakovou, E. (2007): [36]	YES	YES (Environ-mental Issues)	YES	NO	• To tackle the development of efficient capacity planning policies for remanufacturing facilities in reverse supply chains.	• The simulation model provides an experimental tool, which can be used to evaluate alternative long-term capacity planning policies using total supply chain profit as measure of policy effectiveness.
Barber, E. (2008): [3]	NO	YES	YES	YES (BSC)	• To broaden the performance measurements of total supply chain performance.	• A framework is presented showing the importance of intangible value adding aspects of the total value chain.
Georgiadis, P; Besiou, M. (2008): [13]	YES	YES	YES	NO	• To examine the impact of ecological motivation and technological innovations on the long-term behavior of a closed-loop supply chain.	• A system dynamics casual loop diagram for a supply chain of electrical equipment in Greece.
Seuring M, Müller S (2008): [31]	NO	YES	YES	NO	• To present a literature review and to provide a conceptual framework of SSCM.	• Research is dominated by environmental issues. Discussions of social aspects and also the integration of the three dimensions of sustainability are still rarely found.
Hu, G.; Bidanda, B. (2009): [20]	YES	YES	YES	NO	• To formulate a product lifecycle evolution system based on stochastic dynamic programming.	• Conclusions and guidelines for rational decision making is developed through each phase of the product life cycle.
Blecken, A.;Hellingrath, B.;Dangelmaier, W.;Schulz, S. F. (2009): [4]	NO	YES	YES	YES	• To develop a reference model for supply chain processes in the context of humanitarian operations.	• A model that supports humanitarian organizations to visualize their processes, to measure their performance and to improve communication and coordination of their organization.
Capelo, C.; Dias, J.F. (2009):[6]	YES	NO	NO	YES (BSC)	• To develop a theoretical model that explains the effectiveness of the balanced scorecard approach by means of a system dynamics perspective.	• A strategy map review positively influences mental model similarity, and mental model similarity positively influences performance.

Table 2: Analyzed Supply Chain

	CompA	CompB	CompC
Role	Producer	Retailer	Recycling company
Type of business	Manufacturing, filling and refilling of ink cartridges	Purchase of ink cartridges from various manufacturers as well as distribution and sale of the cartridges on the internet.	Collection (installation of collection boxes in schools and universities) / purchase and sorting of empty cartridges / sale of cartridges to the manufacturer or disassembly of the cartridge and processing of material
Total sales	5 million	12.5 million	4 million
Other data used in the model	- number of sold items: approx. 750,000/month - number of environmental certificates: 1	- items sold: approx. 2 million/month	- receipt: 250,000 – 320,000 pcs/month - variable costs per unit: 0.80 – 1.40 €/piece - Sales: 220,000 – 240,000 pcs/month - Price: ø 1.75 €/pcs - disposal: toner: 5,000 – 6,000 €/month - ink cartridges etc.: 2,500 €/month - number of environmental certificates: 5

5. BALANCED SCORECARD FOR SSCM

So-called logistic ratios (also known as Key Performance Indicators (KPIs)) are often applied for the analysis and management of recycling supply chains. The Balanced Scorecard (BSC) is one of the most widespread KPI systems. It takes both quantitative and qualitative parameters into account. Considering that the triple bottom line categories of environmental and social sustainability are also of a qualitative nature, the BSC seems to be a suitable research framework for SSCM. The BSC, which was designed by Robert S. Kaplan (Harvard Business School) and David P. Norton (former head of the Nolan Norton Institute) in the early 1990s, pursues one fundamental objective ([22]): it aims at achieving a balance between several different perspectives (internal process perspective, customer perspective, finance perspective, learning and development perspective) on the basis of targets, KPIs, guidelines and measures.

5.1 Development

There is a variety of suggestions in the literature on how to further develop the Balanced Scorecard. On principle, there are three possible ways to integrate environmental and social aspects into the BSC. The first option would be to integrate them into the four existing perspectives. Also, one or more additional perspectives regarding environmental and social aspects could be newly added to the BSC. Thirdly, a special form of BSC with focus on sustainability aspects could be derived ("Sustainability Balanced Scorecard").

The literature revealed that many researchers propose a combination of the first two possible solutions ([29], p. 78-79.). Some also suggest a non-market perspective encompassing environmental and social aspects that are not regulated by a market mechanism – for example, the working conditions at supplier companies (cf. [11], p. 273-274.). Others integrate environmental and social performance indicators (e.g. emissions) into the existing perspectives ([9], p.75-76.). In addition, researchers take a critical view at the standard Balanced Scorecard for its disregard of social aspects or important topics of environmental management, as e. g. energy efficiency, substance flows, waste and hazardous substances. For these reasons, we recommend to extend the basic BSC concept by including an environmental and a social perspective. The option of adding a non-market perspective is set aside here because those KPIs and interdependencies which have an impact on a company's financial indicators are of more immediate importance for success-oriented management. In return, financial indicators are necessarily market-related and can therefore be integrated into the other perspectives. Beyond that, the authors agree with the frequent recommendation to add a cooperation perspective for BSCs in logistic networks (cf. [5], p. 85). Table 3 shows a BSC for the support of Sustainable Supply Chain Management. The BSC is based on suggestions we found in the literature including KPIs, strategic goals and measures.

Based on the results of the expert interviews on SSCM in recycling networks, the authors selected the KPIs for their BSC: All of the interviewed experts used profit as a top KPI. Furthermore, they measured and monitored their energy and material consumption, they worked with a customer satisfaction index, they coordinated and supervised staff training times and measured the degree to which they use renewable energy sources, and they stated that "certifications" were one of their criteria for selecting suppliers. For the "classic" BSC perspectives 'Stakeholder' (Finance and Customers respectively), 'Processes' and 'Development and Learning', some KPIs were selected on the basis of a recent review by Siepermann and Vockeroth who analyzed existing works on Balanced Scorecards with respect to the used KPIs (cf. [32]). Central KPIs of the cooperation perspective were identified in the context of the expert interviews. The participants regarded compliance with Service Level Agreements, a high supplier delivery performance and the joint use of information systems as important contributing factors for a successful cooperation. By and large, the interview partners confirmed the results of the study. They also reported that the increasing number of network partners with sustainability certifications helped to lower transaction costs for the initiation and realization of cooperations. In particular, it takes less negotiating time to reach agreements on environmental and social standards and guidelines.

Table 3: Balanced Scorecard

Strategic Goals	Reference	Derived KPI for Simulation
Financial perspective		
• Increase profits for the entire supply chain • Save energy, material and recycling costs • Lower transaction costs	• [5]; [29] • [27] • [24], [11]	• profit per month (target: 15% increase) • revenue per month • material costs per month • energy costs per month
Market perspective		
• Increase customer satisfaction with regard to environmental and social dimensions; degree of satisfaction is measured on a scale from 0 (very dissatisfied) to 1 (completely satisfied) • Increase customer retention • Increase the number of sold items	• [29]; [3]; [13] • [24]; [29], [22] • [3]	• customer satisfaction (target value: 0.7) • customer retention • sold items per month
Cooperation perspective		
• Reduce processing times of products along the value chain • Make use of data processing synergies • Connect organizational units to information systems	• [14]; [25]; [32] • [5]; • [25]; [29]	• readiness to deliver (degree) • compliance of service level agreements (degree) • percentage of organizational units who share information systems (target value: 50%) • transaction costs per month (e.g. bargaining costs; target: 15% decrease)
Environmental and social perspective		
• Reduce material and energy consumption by using renewable energy sources • Create a safe and healthy working environment for employees • Support social projects	• [27]; [25]; [12]; [16] • [31] • [25]; [6]	• number of supported social projects (target value REFILLER: 2) • number of environmental certificates (target value REFILLER: 2, target value print cycle: 2) • number of implemented standards for health and safety of employees (target value: 3) • number of used renewable energy sources (target value REFILLER: 2)
Innovation and learning perspective		
• Raise employees' awareness of social and environmental issues • Include employees actively into a continuous improvement process • Use the potential of information systems	• [29] • [32]; [6] • [18]; [27]; [11]	• number of sustainability trainings per month • monthly number of employee suggestions for improvement that are related to sustainability issues • number of hits on information systems per month

5.2 Limitations of the traditional BSC

Primarily, the Balanced Scorecard differs from other performance measurement concepts in the assumption of cause-effect relationships between the key figures ([36], p. 67.). Noerreklit assumes that the relationship between the key figures are not based on causality, but on interdependence ([28], p. 7.). However, this implies that the relations are not unidirectional, but also reflexive, ambiguous and complex. Thus, the BSC loses much of its capability as an instrument for SSCM. The complexity of the SSCM requires a simultaneous consideration of the environmental, social and financial dimension. Considering the fact that in the BSC these dimensions are reduced to single key figures, the complexity inherent in the concept of sustainability may not be sufficiently considered.

The BSC also provides little support in deriving concrete measures from the strategic objectives. Interactions and feedback loops between factors should be revealed in order to define appropriate measures ([8], p. 932). In addition, managers should preconceive the amount of time it takes to trigger certain effects. What short-term effects do occur and what long-term reactions and feedbacks are expected? Although Kaplan and Norton point to a dynamic business development, the BSC does not explicitly take this aspect into account [36].

As a further limitation, the metrics of the BSC particularly refer to the internal corporate perspective. This could be problematic because external factors might influence the SSCM. For example, the activities of competitors or technological developments could influence the expectations of customers, e. g. the customer demand for electrically powered cars.

6. Enhancement of the BSC by System Dynamics

System dynamics is an approach that follows the principles of systems theory. It has the objective of optimizing systems in dynamic and complex environments ([8], p. 10). In contrast to linear thinking, system dynamics points out the inherent complexity and non-linearity of systems. According to this approach, main characteristics of systems are delayed cause-effect relationships and feedback mechanisms ([12], p. 245). Considering these characteristics, we assume that system dynamics could be an adequate method to overcome the limitations of the traditional BSC ([8], p. 933). Therefore, we decided to follow the system dynamics approach in carrying out the simulation experiments. The Balanced Scorecard for SSCM introduced in Section 3 serves as a framework for the simulation model. The KPIs function as mutually interdependent model elements. The plus sign beside the arrowhead stands for a proportional relationship: if variable a increases, variable b increases accordingly. The minus sign indicates an inverse proportional relationship: if variable c increases, variable d decreases. A mathematical function underlies each arrow. As opposed to the BSC, the interdependencies between the KPIs are quantified here. A simplified illustration of the model is provided in Figure 2. For the sake of clarity, the authors have erased auxiliary quantities which were merely introduced to support the technical implementation of the simulation experiments.

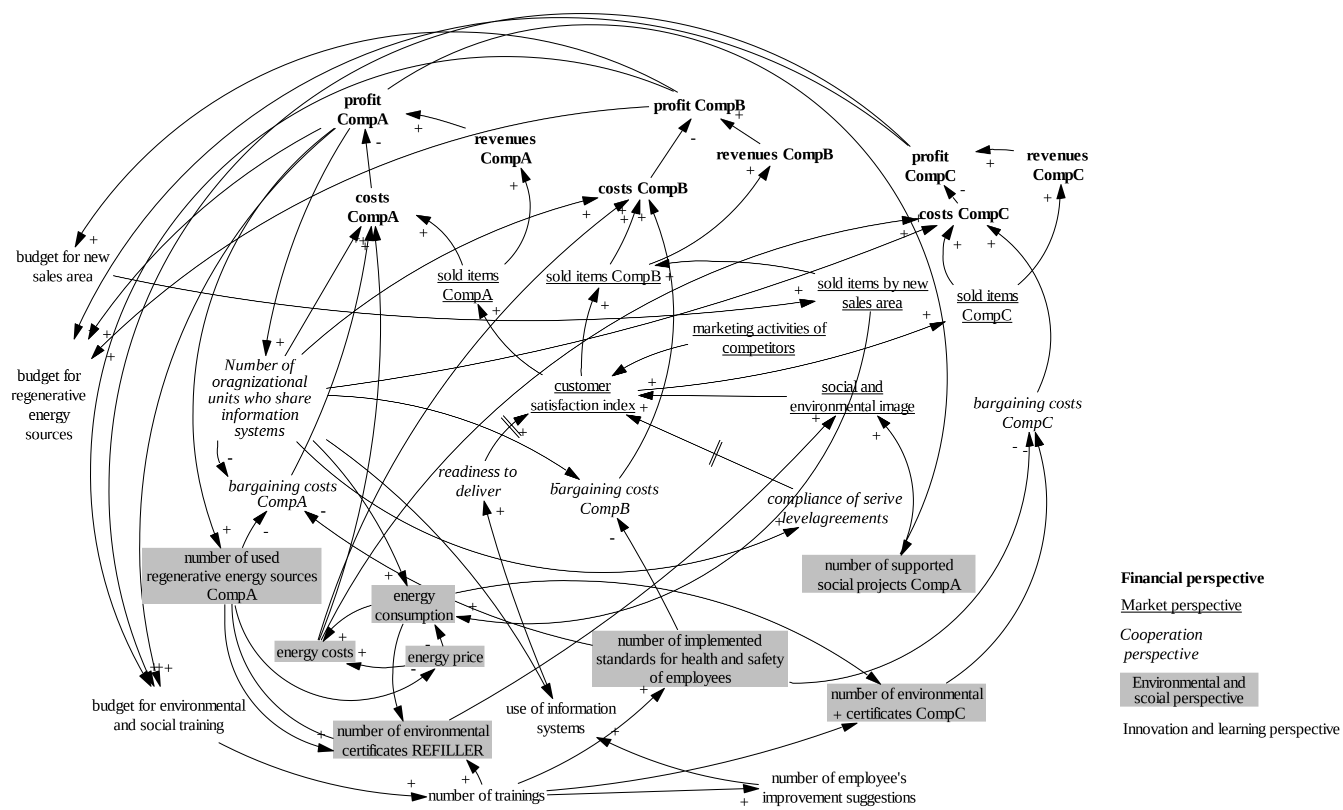

Figure 2: Simulation Model

The supply chain introduced in Section 4 is modeled here. For the companies „CompA“, „CompB“ and „CompC“, profit (a variable that can be defined as the difference between revenues and costs) is simulated as top KPI. These financial KPIs directly depend on the numbers of sold ink cartridges. In return, the number of sold items depends to a great extent on customer satisfaction. Also, lower bargaining costs lead to higher profits. As regards the cooperation perspective, the more organizational units share information systems and the more environmental certificates a company acquires, the lower are the bargaining costs. Certificates serve companies to quickly build up mutual trust – for example, reliance on the partners' compliance with environmental standards. The number of environmental as well as health and safety standards that a company adheres to and the number of social projects it supports have a positive impact on the corporate image and customer satisfaction. The number of obtained certificates and introduced standards depends significantly on the available budget. In the illustrated example, part of the profit is periodically invested in training measures that enable the staff to manage processes in an environmentally and socially responsible way. A second portion is invested in IT networking with supply chain partners and a third one in renewable energy sources. A fourth portion is invested in building new sales areas. The investments in IT networks as well as the investments in new sales areas result in an increased overall energy consumption. This leads to higher energy prices resulting from increased demand. The price increase is mitigated by a higher energy supply, which is due to the recourse to renewable energy. The question arises whether these sustainability investments are economically beneficial, i. e. whether an improved corporate image and increased customer satisfaction generate higher sales figures and profits. Another question is whether the use of regenerative energy contributes to environmental protection. To look further into these questions, the following three Scenarios are simulated:

Scenario 1: This is the basic Scenario. All basic values and assumptions in the model are available at the following address: www.uwi.uos.de/assumptions.pdf

The other two Scenarios show the following modifications:

Scenario 2: The budget for renewable energy sources is increased from 0.5% to 8% of the profit, and the budget for the development of information systems increased from 0.5% to 1.25%. The budget for sustainability training and social projects is increased from 0.3% to 1% of the profit.

Scenario 3: With regard to Scenario 2 it is assumed that CompB invests 20% of its profits into the building of new sales areas in order to increase its revenues. In addition, the corporate image only improves after the acquisition of five – instead of two – environmental certifications. It is therefore assumed that only very extensive investments in sustainability measures are recognized on the market.

7. RESULTS

The Scenarios were simulated for a time span of 120 months (10 years). The profit development of the three supply chain partners, the levels of customer satisfaction and the overall energy consumption are illustrated in Figure 3.

A PDF document that includes the simulation results shown in Figure 3 is available at the following address: www.uwi.uos.de/simulation_results.pdf

In the first (basic) Scenario, the three supply chain partners' profits largely remain constant throughout the simulated time span of 10 years. Each network partner makes profits which are invested in sustainable development measures. Within the simulated time frame, the customer satisfaction index rises slightly from 0.5 to 0.6. However, this moderate rise does not suffice to generate a significantly higher number of sold items. The overall energy consumption increases slightly from 5 MWh to 5.2 MWh. The results of Scenario 2 show a 53% profit increase for the CompA after 90 months: the amount rises from about 550.000 € to ca. 850.000 €. This result clearly exceeds the original target of a 15% rise. CompB also increases its profits. From period 90 onwards, a profit of about 2.3 m € is generated. In comparison to Scenario 1, this equals an increase of ca. 30%. The profits of CompC fluctuate, but show a generally rising tendency. Compared to Scenario 1, the average profit increases from 33.000 € to 51.000 € per period, which equals a 54% rise. The clear increase in customer satisfaction (up to 0.85% in period 90) leads to higher sales figures, revenues and profits for all three network partners. The raised costs of environmental and social measures are therefore overcompensated by higher profit rates. Thus, sustainability investments pay off for all network partners. The energy consumption is around 3 kWh higher than in the first Scenario. On the one hand, the development of the IT environment requires more energy and on the other hand, the addition of renewable energy sources leads to an increased supply on the market. The increased supply leads to lower prices which in turn stimulate increased demand. In the literature such effects are described as rebound effects (cf. [31]). More precisely, Scenario 2 demonstrates a so-called "*market-clearing price and quantity adjustment*" ([65], p. 86). This term describes the phenomenon of one company's energy savings resulting in higher energy consumption by other companies. In our example, CompA's use of renewable energy sources leads to a lower demand for conventionally generated energy. The resulting increased supply of conventional energy forms on the market causes a price drop and, in consequence, the company's demand for conventional energy increases again. In the third Scenario, the three network partners' profits are only slightly higher than in Scenario 1 and clearly lower than in Scenario 2. In comparison to Scenario 1, CompA's average profit increases by about 3%, the profit of CompB by 5% and the profit of CompC by about 2%. Customer satisfaction slightly increases to 0.6% because the growing expectations of the market act as a counterbalance to image improvement. Thus, it becomes clear that there are significant interdependencies between sustainability measures, the public image of the network partners and customer satisfaction. Even slight variations in the intensity of these effects have a noticeable impact on the achieved profits. It therefore depends decisively on the customer whether social and environmental investments pay off financially. Sustainability measures only lead to higher profits if customers become aware of these efforts and, in reaction to this, increase their demand for sustainable products.

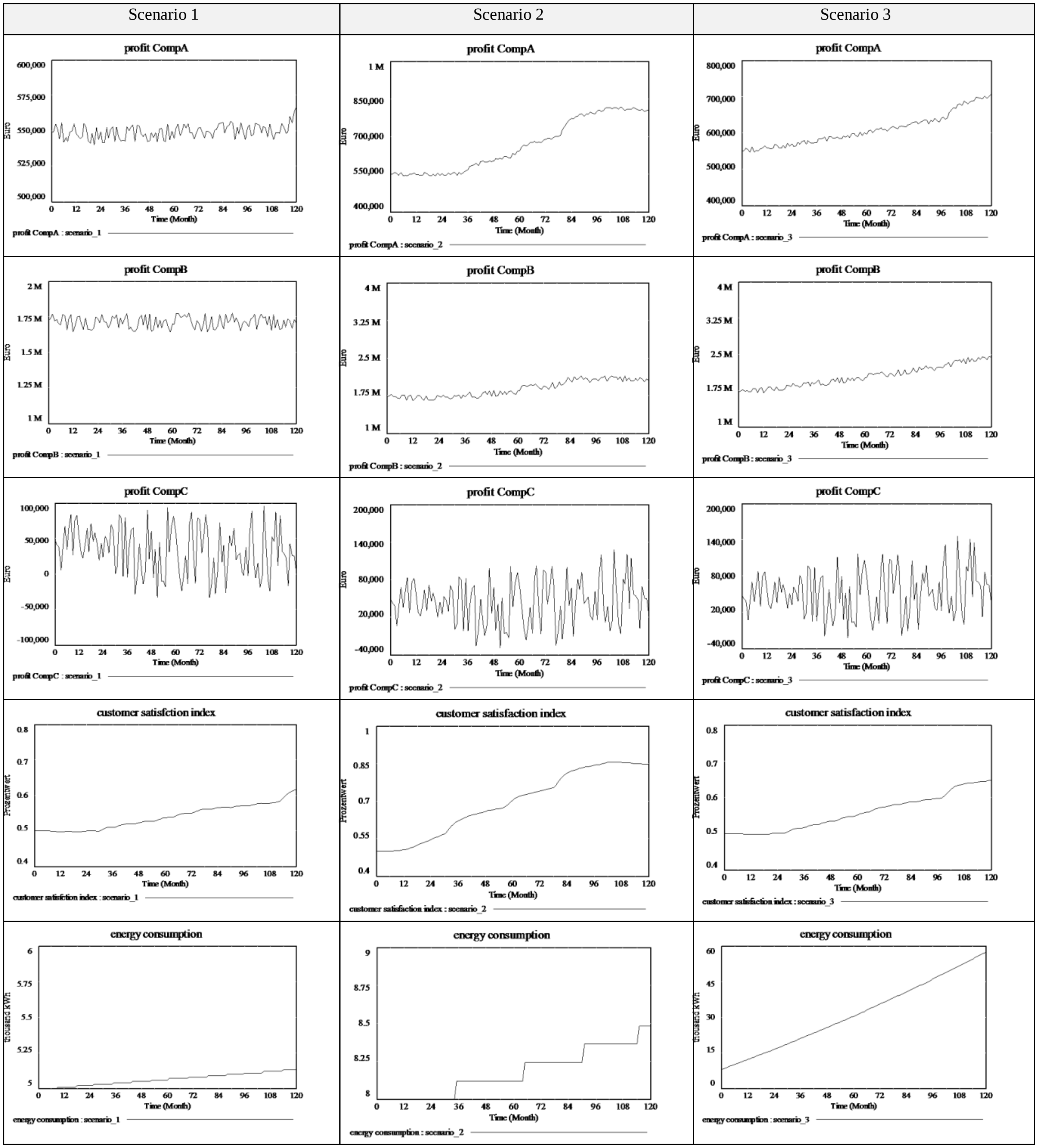

Figure 3: Results

Scenario 3 shows a significant rise in energy consumption: CompB invests the profits gained through energy savings in the development of new sales areas, which in turn cause a strong increase in energy consumption. Thus, in the end, the overall energy consumption is raised instead of lowered. This rebound effect, which is also known as “income effect” ([16], p. 68), is a phenomenon frequently observed in practice.

8. CONCLUSION

The simulation model described here was designed to illustrate the potential benefits of an enhanced BSC that includes a system dynamics dimension for the support of SSCM. Although the approach has proved to be beneficial in several ways, there are also some limitations to it.

8.1 Limitations of the Model

The presented system dynamics model is not a “black box”: processes and their impact on other parameters, as well as the temporal behavior of SSCM mechanisms in an exemplary recycling supply chain, become transparent during simulation runs. There are various alternative ways in which a BSC and the model constructs in system dynamics models can be designed. Wherever possible, expert knowledge gained from interviews, empirical data and existing (case) studies was drawn upon to increase the objectivity of the model and the BSC. Still, it needs to be pointed out that the presented model should be understood as ideal-typical: its structure cannot capture the reality of SSCM in all its complexity. The authors of this paper followed the KISS approach (KISS = "keep it simple and stupid", cf. [36]) in constructing a basic system dynamics model that is designed to be gradually refined and extended.

The more intricate a model is, the harder it gets for its constructor to understand how the system behaves in time, and to grasp the reasons for this behavior (cf. [1], p. 413.). With growing model complexity, the danger of misinterpreting simulation results increases. For example, what conclusions can be drawn if a strong imbalance occurs in the model although only one parameter has been modified? Depending on their particular perspective, researchers can arrive at different explanations for such unexpected effects: sometimes, the whole model ends up being dismissed as invalid and unrealistic. As a consequence, the model assumptions need to be modified until the sensitivity disappears (cf. [22], pp. 38-41.). Others understand such “chaotic” imbalances as indicators of real-life risks and uncertainties, which have an early warning function for SSCM.

The simulation time of 120 months corresponds to the typical length of a strategic planning period. This long timespan may increase the probability of structural interruptions, but in the context of this work it is less important to calculate exact results than to reach a basic understanding of the system’s behavior.

8.2 Advantagesof System Dynamics

We identified the following benefits of system dynamics which can serve to overcome the described limitations of the traditional BSC:

According to the system dynamics approach, interactions and "feedback loops", i. e. feedback relationships between the elements, are essential system components. This was illustrated by rebound effects in the exemplary model. If one of the exemplary supply chain partners reduces its energy consumption, this leads to a short-term decline in demand. In the long run, this measure results in falling prices and a higher energy demand of the other supply chain partners. The feedback structures suggest that a focus on cause-effect relationships is not adequate in the context of SSCM. In reality, a company’s reaction to changes is not fully predictable. External impulses from the business environment encourage a company to act in a certain way. Our exemplary model may show the desired behavior, but there can be no certainty that in reality everything will happen exactly as planned and calculated. Decision makers need to take this into account by specifying probabilities for SSCM.

It has been argued that the BSC does not support the top-down implementation of strategies into operational measures. Here, system dynamics offers a solution: through the quantification of relations between the model elements, the strategic objectives are directly linked to the operational metrics. In this way, operational activities can be derived and evaluated. As shown in the model, the effects of concrete measures to increase customer satisfaction can be compared and analyzed.

In addition, it becomes obvious that effects of investments can be analyzed time-dependent by performing simulation experiments according to the system dynamics approach. For instance, in deciding whether and how intensively employees should be trained in SSCM, time delays could be differentiated. As shown in Scenario 2, the training does not have any noticeable positive effect on the profit until period 50, while the negative effect (training costs) diminishes the profit immediately.

System dynamics can also help to widen the predominantly internal perspective of the traditional BSC by expanding the system boundaries. In this way, external factors can be accounted for. Thus, in the exemplary model, the advertising activities of the competitors are included as external variables. These variables might be important for following reason: A decreased customer base could be the result of extensive advertising activities of competitors. Some researchers have criticized that the traditional BSC does not support the identification of new success factors or new risks. This cannot be expected of system dynamics either. In the simulation model, only the previously defined factors are considered. However, at least a predefined set of potential risks and uncertainties can be disclosed and the factors can be tested for their risk potential. In this sense, simulation results can provide hints for decision support in SSCM.

The analysis of the behavior of a system dynamics supply chain model leads to the conclusion that the system behaves in the way it was programmed to. If structures and sizes are assumed, effects can be calculated and predicted. It is important to remember, however, that the definition of metrics is based on subjective decisions of the modeler, however reasonable and plausible they may be. Thus, the model can be described as a code-compliant system without external influences. On the other hand, real business environments are characterized by unpredictability. Hence, the benefit that decision makers may expect from using the proposed enhanced BSC is remarkable, but limited. For example, managers who wish to assess the impact that improvement measures in the field of SSCM have on the system behavior will have to live with probabilities instead of certainties.

The advantages of system dynamics compared to the traditional BSC are summarized in Table 4.

Table 4: BSC and Advantages of System Dynamics

Limitations of the BSC	Advantages of System Dynamics
• The concept of causality excludes empirical validation, unidirectional relationships between perspectives as well as monocausal cause-effect relationships between key figures	• Correlations are quantified; validation is difficult; feedback loops and rebounds are closer to the company's reality
• Derivation of measures for strategic objectives is not faciliated	• Material and information flows are directly related to the objectives and could be derived; however, the response of the system to individual measures cannot be exactly predicted
• Lack of dynamics	• Delays allow for a differentiation between short-and long-term effects
• Primarily internal perspective	• External variables can be modeled
• Risks and uncertainties are not considered	• Probability distributions and Scenario analysis allow for the evaluation of a predefined set of risks and uncertainties

8.3 Further Research

There is further need for empirical research on the interrelations between financial and non-financial figures. The model presented here has revealed the customer satisfaction index as a central figure, based on the assumption that environmental measures and the responsible treatment of staff increase customer satisfaction and turnover. It seems promising to conduct further research on the interdependencies between sustainability investments and customer satisfaction on the one hand and between customer satisfaction and turnover on the other hand. Longitudinal studies appear to be an especially suitable method, for they can provide insights on changing interdependencies over a prolonged period of time. Annually repeated studies could reveal shifts in the weighting of the three dimensions of sustainability. For example, is the significance of environmental or social goals increasing or declining? Also, rebound effects can be identified and analyzed if data are collected over several periods. Data collection could focus on the areas into which companies invest the savings achieved through increased energy efficiency. Which effects do these measures have on the environment and the total energy consumption of an economy? Analyses of that kind will be part of our future research work.

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