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Environmental supply chain management: using life cycle assessment to structure supply chains

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Abstract

In recent years increasing attention has been given to environmental supply chain management (ESCM). One of the supporting instruments of ESCM is life cycle assessment (LCA). The idea of integrating LCA into supply chains is gaining more support among research institutes and companies. However, we conclude that there are no guidelines for this integration. In this paper we argue that in-line with a differentiation between environmental care chain strategies and environmental chain performances, a differentiation between types of LCAs should be made; i.e., between compliance-, process- and market-oriented LCAs. To execute these different types of LCAs, the chain structure should be attuned to meet the specific requirements of these types. By discussing case studies, we show that the integration of the different types of LCAs in a chain bring about different chain structures. © 2002 Elsevier Science Inc. All rights reserved.

1. Introduction

One of the most significant paradigm shifts of modern business management is that individual businesses no longer compete as solely autonomous entities, but rather as supply chains (Christopher, 1998). Strictly speaking, the supply chain is not a chain of businesses with one-to-one, business-to-business relationships, but a network of multiple businesses and relationships. Executives are becoming aware that the successful co-ordination, integration and management of key business processes across members of the supply chain will determine the ultimate success of the single enterprise (van der Vorst, 2000). The need for

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successful linkages holds true especially in food supply chains because of the shelf life constraints of food products and increased consumer attention to safe and environment- and animal-friendly production methods (Boehlje, Akridge, & Downey, 1995). One only needs to refer to recent problems concerning BSE, foot-and-mouth decease and swine fever in Europe to picture the numerous inter-relationships of actors in these networks. Lambert and Cooper (2000) underline this growing awareness of executives in their research agenda for supply chain management (SCM). According to them, a top priority in SCM should be research to develop a normative model that can guide managers in their efforts to develop and manage their supply chains.

Recently, more attention has been given to environmental supply chain management (ESCM) defined as "the set of supply chain management policies held, actions taken, and relationships formed in response to concerns related to the natural environment with regard to the design, acquisition, production, distribution, use, reuse, and disposal of the firm's goods and services" (Zsidisin & Siferd, 2001). Life cycle assessment (LCA) can be seen as the main instrument of ESCM; it is a technique for gathering data on environmental care issues, which can be used to restructure supply chains in order to improve the environmental performance of those supply chains. In general, the steps to be taken to implement LCA are well described (ISO, 1997). However, when one develops a LCA from different perspectives and with different goals, different results are obtained; LCA is therefore a context-dependent tool.

Furthermore, the fulfillment of environmental objectives by applying LCA requires specific ways of working and forms of co-operation in the supply chain. Organizations can strive for different ambition levels of environmental care. We argue that these levels are best suited to different supply chain structures.

Fig. 1 depicts our line of thought. Actors within a supply chain pursue a certain environmental care strategy; when all actors agree on that strategy one can state that there is a 'supply chain environmental care strategy.' This strategy is operationalized into a number of environmental performance indicators. When different strategies are pursued, different performance indicators emerge and/or different weighting is given to each indicator. Therefore, we can discern different types of environmental performances.'

When a supply chain strives to realize specific performance objectives, one specific supply chain structure is more suitable than the other. Actors within the supply chain require information concerning emissions, products and processes in order to control, manage and steer the chain in the direction of its goals. LCA provides information to measure the environmental supply chain performance; however, not all information is suitable in all situations. Certain parts of the LCA are more suitable when certain environmental objectives are pursued than other parts. This leads us to the following problem statement:

1. What (selection of the) LCA data is required when a certain environmental care strategy is adhered to? How should LCA be used?
2. What types of environmental performance objectives can be distinguished?
3. What supply chain structure is (most) appropriate for realizing those objectives?

By answering these research questions, we hope to contribute to theory and practice directed towards:

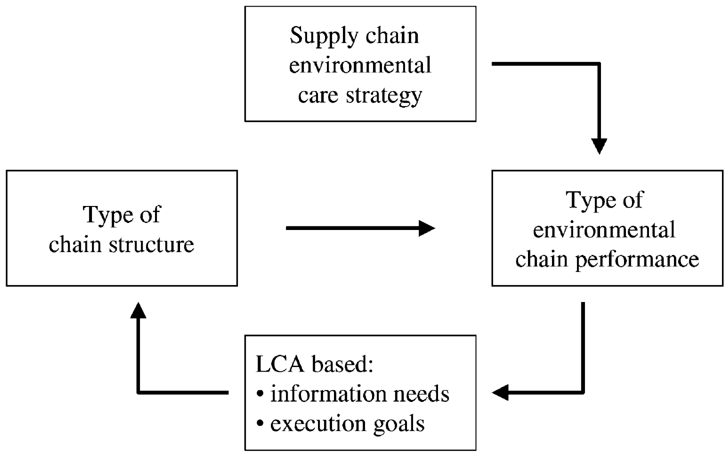

Fig. 1. Research model.

- developing guidelines for managers in their efforts to develop supply chains from an environmental perspective;
- relating the environmental supply chain to its environmental performance;
- assessing the applicability of LCA as a tool for (E)SCM.

In the following sections we will elaborate on the terms used. Section 2 discusses supply chain management and partnership. Section 3 focuses on LCA. Environmental care strategies leading to types of LCA and required supply chain capabilities are the subject of Section 4. Section 5 discusses the requirements supply chain structures have to meet in order to implement the different types of LCA. Section 6 presents four types of supply chain co-operation structures and Section 7 discusses some case examples. The final section presents our conclusions.

2. Supply chain management

Over the years, several definitions have been developed to describe chain co-operation. At this stage there seems to be no single universally accepted definition which generally covers the field of interest (Migchels, 2001). The following descriptions have come out of the debate:

- "... organizations that commit themselves, based on expectations of consumers, stakeholders and physical dependencies" (Beers, Beulens, & van Dalen, 1998).
- "By focusing on consumer needs a temporary and partial network will develop of common activities and exchange of people, resources and information" (Zuurbier, Trienekens, & Ziggers, 1996).
- "The integration of business processes from consumer to the original suppliers leads to product-service information that has added value to customers" (Cooper, Lambert, & Pagh, 1997).

Fig. 2. Typology of supply chain partnerships.

These definitions may differ in many respects as they are designed to limit a particular field of research or to fit a specific situation. However, commonalties can still be found. Key aspects that are included in many of the definitions of chain co-operation are (Migchels, 2001): a network of several organizations; processes and transactions; achieve better results; control and co-ordination; vertically organized; consumer oriented; flexible, non-integrated organization. Within the supply chain, relationships may take on a variety of legal forms, including vertical integration, long-term contracts, and market transactions. Cooper and Ellram (1993) view SCM as lying between fully vertically integrated systems and those in which each channel member operates completely independently (Fig. 2). In strategic partnerships the emphasis is on co-operation and partnership between the parties, not competition and conflict, as the basis upon which a joint competitive advantage is developed. Partnership refers to a relationship that attempts to build interdependence, enhance co-ordination, improve market position focus (by broadening or deepening), or to achieve other shared goals; and that entails sharing benefits and burdens over some agreed time horizon (Cooper & Gardner, 1993). A partnership is a tailored business relationship featuring mutual trust, openness, and shared risk and reward that yields strategic competitive advantage (Handfield & Nichols, 1999). ESCM pre-supposes information about all production stages of the product life in order to be more effective from an environmental perspective. It requires data transparency and policy congruence in the supply chain, and therefore openness and trust.

Table 1 combines the findings of literature on partnerships in marketing, contract law, economics and logistics (Cooper & Gardner, 1993; Zuurbier, Trienekens, & Ziggers, 1996;

Table 1
Critical success factors for partnerships

Drivers for partnerships	Main partnership facilitators	Successful partnership characteristics
Asset-cost efficiencies (cost reduction)	Strategic complementarity.	Joint planning.
Customer service (e.g., shorter cycle times)	Corporate compatibility (culture and business goals)	Global SC operating controls.
Marketing advantage (e.g., entrance into new markets)	Compatibility of managerial philosophy and techniques.	Systematic operational information exchange (rapid and accurate transfer)
Profit stability/growth	Mutuality (joint objectives, sharing of sensitive information)	Sharing of benefits/burdens.
	Symmetry in power.	Trust and commitment.
		Extendedness (the relationship will continue into the future)
		Corporate culture bridge-building.

Simpson & Long, 1998; Lambert, Cooper, & Pagh, 1998). It provides an overview of aspects mentioned in literature that are relevant in determining if a partnership is appropriate. Because each relationship has its own set of motivating factors driving its development as well as its own unique operating environment, the duration, breadth, strength and closeness of the partnership will vary from case-to-case and over time.

We conclude from this short review of SCM literature that there is variation in the motivations, facilitators and success characteristics needed to develop and maintain supply chains. This differentiation in partnerships must be incorporated in the fine tuning between the LCA to be executed and the supply chain structure.

3. Life cycle assessment

Life cycle assessment is an instrument with which environmental effects of a product during its life cycle can be integrally assessed. Integral means that all the processes in the supply chain that contribute to the overall environmental burden are incorporated in the assessment; from the use of raw material to the use, re-use and disposal of the product. Unfortunately, there is no standard way of executing an LCA, and there are many varying definitions (van Koppen, 2000). The most authoritative definition of LCA at the moment is the ISO 1,4040 definition (ISO, 1997). In this ISO "code of practice", the LCA is divided into the following four main steps:

1. *Goal definition and determination of the scope*: This step identifies the questions that have to be answered by the LCA. The goal (for example, benchmarking of comparable products or identifying the contribution of different process steps) and the scope (the level of detail of information) are determined. An important element is the demarcation of the functional unit, i.e., the unit of measure that quantitatively reproduces the function of the product under investigation (for example, '*x* grams of fat' related to nutritional value). This unit is the central measure for the analyses of the environmental burden.
2. *Inventory analysis*: All processes that contribute to the environmental burden are inventoried. For each process the emissions, the mining of raw materials, the input of other products and the output of economic products are mapped and registered into an environmental data sheet.
3. *Impact assessment*: In this phase, the impact of the environmental measures (e.g., the emissions) on the environment are estimated by linking the environmental measure with environmental themes such as global warming, ozone depletion or nitrification.
4. *Interpretation*: The results of the inventory and impact assessment are interpreted by the researchers from the perspective of the goal and scope definition.

This seems to be a clear-cut approach of gathering environmental data, but in literature we can find quit a few problems and ambiguous moments of choice in the execution of LCAs (Bras-Klapwijk, 1999):

- *Representativeness and legitimacy*: The question arises whether or not the LCA method results in a realistic reflection of the sustainability of chains. Missing data, calculation errors and disputable assumptions in the demarcation of the functional unit as well as in the choices underlying the participation of environmental themes and the weighing of those themes can cloud one's view of the environmental aspect of a chain. Considering these disturbing factors one can conclude that an LCA does not provide absolute values (van der Kolk, 1995).
- *Specific usefulness*: Fraanje and Lindeijer (1993) state that the quality and usefulness of LCA leave a lot to be desired because of missing and/or obsolete data, disputable assumptions, the lack of important alternatives and a poor aggregation of data. The lack of an environmental theme can be a problem when we want to reach a global representative result, but in the case of companies who want to optimize their environmental performance it should not be a problem. In the case of specific company or chain goals, the problem can lie in the fact that LCA databases are filled with average industry data. On the basis of such a global data-set, it is difficult to choose a specific supplier for a specific company.
- *Return*: Schaltegger (1996) states that the current application of LCA is low on cost-efficiency. The gathering of data for specific chains is very expensive. On the other hand, databases filled with average industry data can easily lead to wrong management choices in specific companies and chains.
- *Comprehension and transparency*: The more complex the LCA, the less transparent and comprehensive it is for not environmental specialists. This incomprehension can lead to two kinds of communicative problems: between the environmental staff and the general manager (see Schuster, 1998) and between the company and the consumer. Transparency depicts the level at which other parties have an inward view on the companies' processes. This view can be at odds with the confidentiality of the data in relation to the competitive position.

From a managerial perspective, we can conclude that the application of the LCA instrument is not without problems. Choices have to be made about the amount of resources one intends to invest in the execution of an LCA, about the required information to make far-reaching decisions including implementation, about the required information to satisfy stakeholders and, finally, about the publishability of information. These are all questions that have to be answered in order to be able to use the LCA instrument in the company or the chain. A strategic choice has to be made in relation to the application of LCA. Strategic because there has to be a trade-off between the process lay-out, the co-operation intensity with suppliers and buyers, and the relation with the customers and other stakeholders.

4. Environmental care strategies, types of LCA and supply chains

The previous paragraphs referred several times to the fact that different organizations strive for different goals, which impacts the type of LCA that is most suitable in a specific situation. But what environmental care strategies are possible? A literature research resulted in the following typology of environmental care strategies applicable to individual companies and supply chains (e.g., Vermaak, 1995; Spliethoff & van der Kolk, 1991; van Koppen & Hagelaar, 1998):

- *Compliance-oriented strategy*: Comply to rules and regulations with the help of end-of-pipe techniques. Perfect examples of compliance-oriented measures are a water clearance installation and filters on chimneys to diminish a particular kind of emission.
- *Process-oriented strategy*: Strive for control of the environmental burden caused by the production process by means of production integrated measures that achieve both compliance with governmental rules and regulations and a better return (pollution prevention pays). Examples of process-oriented measures are new technologies to save water or other raw materials or a process redesign to accomplish less waste during the production process.
- *Market-oriented strategy*: Aim for the reduction of the environmental burden caused by the design of the product to achieve competitive advantage. In this stage of environmental care the R&D department also incorporates the environmental aspects in the design process.

These environmental care strategies are linked in an ideal-typical way to specific characteristics of a company or supply chain. Table 2 presents this linkage on an aggregate level. It can be seen that different environmental care strategies require different organizational capabilities.

In a supply chain, strategic choices have to be made concerning the chain's environmental goals. This implies that whenever the goals vary, the information needed to take decisions will vary as well. Therefore, the goals serve as selection criteria for the LCA data needed.

Table 2
Environmental care strategies and organizational characteristics (van Koppen & Hagelaar, 1998)

Characteristics	Compliance	Process	Market
Internal			
Knowledge	Knowledge about some, prescriptive, aspects	Knowledge about production process aspects	Knowledge about the product supply chain
Information	Little horizontal and vertical information sharing	Information sharing on tactical and operational level	Information sharing on strategic level
Technology	End-of-pipe technology	Process-integrated technology	Product design technology
Structure	Few and isolated tasks	Explicit tasks on the tactical and operational level	Integrated tasks on different levels including staff level
Budget	Budget is small	Budget for investments with a long term pay-back period	Budget for strategic investments
External			
Risks	Risks are deduced from the rules and regulations	Risks are limited and/or changeable	Risks become challenges
Opportunities	No opportunities	Opportunities through cost savings	Market opportunities

Based on this assumption, we want to differentiate between the following types of LCA and data required:

- *Compliance-oriented LCA*: End-of-pipe data (emissions, etc.).
- *Process-oriented LCA*: End-of-pipe, process steps, and transport data.
- *Market-oriented LCA*: End-of-pipe, process steps, transport, nature and quantity of raw materials, and disposal data.

When the environmental care strategy becomes more ambitious, the LCA has to generate much more detailed information. The information gathering tends to progress from the outskirts of the organization (compliance), into the factory (process) and, finally, into the product (market). To be able to gather such detailed information in a reliable and efficient way, increasing demands are placed on the co-operation of the companies involved in the supply chain.

5. LCA implementation requirements

Multiple decisions concerning the scope of measures that reduce the environmental burden are possible. The LCA can trigger individual companies to implement such measures; it can also result in a joint effort in a specific place in the supply chain; it can even result in a joint decision for a changed product design (see van Sonsbeek, van Beek, Urlings, Bijker, & Hagelaar, 1997). It is clear that in order to make such joint decisions, some form of chain co-operation is required.

A chain is organized according to the collective targets of the participating companies and the conditions they agreed upon (Zuurbier & Hagelaar, 2000). In talking about multi-actor supply chains, we should be keep in mind that not all chains are identical; external and internal demands on chains can differ and it is within this environment that chains are designed. In order to typify a supply chain, we will distinguish between three inter-related components of a supply chain that are specifically designed to meet those internal and external demands: institution, process and performance (see Trienekens, 1999; Mintzberg, 1983). *Institution* refers to the companies in the supply chain and the relations between them. The *process* refers to the sequence of activities of the parties involved. Finally, *performance* refers to the common objective of the chain (Trienekens, 1999).

In this paper, performance refers to the aimed environmental performance. It is defined as the result of the combination of the physical processes in the supply chain and the organization which controls, manages and steers these physical processes. To fulfill the environmental performance objectives, the process and organization should be designed in a specific way. Therefore, it follows that each type of LCA requires its own type of process and institution to fulfill its specific performance objectives (Table 3).

We will discuss the two opposite types of LCA. The *compliance-oriented type of LCA* is directed towards the individual links in the chain. Every specific party in the chain has to comply to rules and regulations that define a basic norm, which should not be surpassed. The process is not important in this type of LCA; it remains a black box because the attention is

Table 3
Supply chain requirements of LCA types

Components SC	Types of LCA		
	Compliance oriented	Process oriented	Market oriented
Institution	Fragmented	Negotiation	Communal
Process	Black box: identification of outside effects (emissions, etc.)	Nucleus: identification of internal effects and causes	Sublimation: identification of contributions to the meta-result of the process
Performance	Compilation of results of individual end-of-pipe measures	Compilation of results of end-of-pipe measures and realized process improvements	Compilation of results of end-of-pipe measures, process and product design improvements

directed towards emissions, etc. The chain is a fragmented organization since each company should individually comply to the (governmental) demands directed specifically at it. The chain environmental performance in the compliance case is measured in the compilation of all individual performances.

The *market-oriented type of LCA* is the mirror image of the former. The environmental performance is the result of the joint effort to design and produce a product. This requires a chain structure in which the individual links work intensively together to open new markets. Integration and common goals are key aspects. The ultimate result of the well co-ordinated process steps in this kind of chain structure is the integral level of analysis.

We can conclude that as the ambition level for the use of LCA increases, the chain requirements also increase in order to fulfill the higher environmental performance objectives. The final step in our research model is to differentiate between supply chain co-operation structures and to match these with the three types of LCAs.

6. Supply chain co-operation structures

We distinguish between four types of supply chain co-operation based on two dimensions (Fig. 3):

1. The extent of *complexity* of the supply chain partnership, as defined by the number of functions (logistics, marketing, etc.) that are included in the partnership.
2. The *differentiation* of the structural linkage between the partners in the supply chain, defined as the number of consult structures between partners which influence the decision making process.

The *round table structure* is the most basic. There are few consult structures between partners influencing the decision making processes focused on only one business function (e.g., transportation). All the other business functions and management functions are dealt with by each individual partner separately.

The *multi-focus simple structure* suggests that few consult structures between partners participate jointly in the decision making processes on several functions. Within each firm,

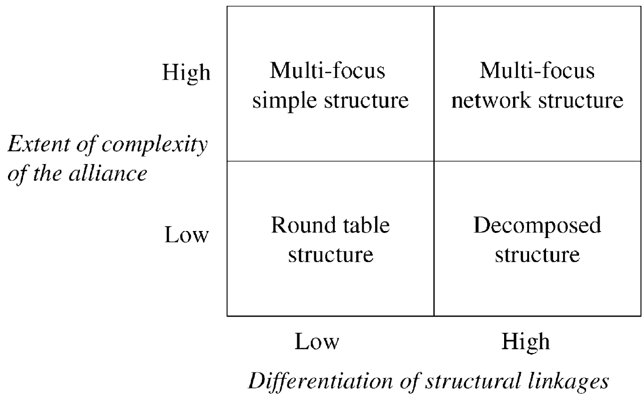

Fig. 3. Typology of supply chain structure.

the decision making is attuned to the joint decision making. This situation is very close to the hierarchical structure, in which departments have small decision areas.

The *decomposed structure* is characterized by just a limited number of functions to be included in the partnership. However, the nature of those functions requires a highly differentiated consult structure of co-ordination and fine tuning among the partners, horizontally and vertically. This situation occurs for example in highly technologically advanced alliances.

The last structure, the *multi-focus network structure*, fits situations in which the partnership deals with many functions and the decision making process is highly differentiated both vertically and horizontally. Mechanisms that are installed in these structures comprise: joint teams for individual functions, shared facilities, inter-functional and cross-functional interfaces, steering mechanisms for overall managing of the alliance or supply chain, and centralized and decentralized decision making based on decomposition of problems (see Zuurbier & Hagelaar, 2000). In short, this is ESCM in *optima forma*.

7. Case studies

In order to position our findings in practice, two illustrative case studies are presented. The first case study exemplifies the round table structure, the second the multi-focus network structure. Based on these and other case studies, Section 7.3 discusses the relation between the type of LCA and the required chain co-operation structure.

7.1. The slaughter by-product chain

The tendency to debone and portion carcasses at slaughterhouses to meet the retailers and consumers demand for ready to eat products and convenience foods, means also a concentration of the production of by-products. The volume of these by-products is significant as it is calculated as 40% and 20% of the live weight for poultry and pigs, respectively, mainly consigned to animal nutrition (van Sonsbeek et al., 1997).

The slaughter by-product chain comprises the following participants: a slaughterhouse, a central rendered and an animal feed processor that transforms raw materials into feed components. The chain as a whole has various environmental problems. The slaughterhouse has odor problems in general, significant water use resulting in large amounts of waste water (which also creates odor problems and sludge), and high energy usage. The rendered processes high risk material and it has odor problems. The animal feed processor also has odor problems and high energy and water usage.

A detailed supply chain analysis pointed towards the compliance level as leading environmental care strategy; in particular, because of the external risks, the internal organization structures (very isolated tasks) and the little information sharing between organizations involved (see Table 2). However, the companies were anxious to know about potential cost savings by means of process integrated measures.

With the help of scenario-analysis LCA scenarios were constructed on a compliance level (every company dealing with its own problems) and on a process level (process measures on a chain level such as sorting materials at the slaughter house to reduce problems at the central rendered and the animal feed processor). Mainly because of a lack of trust between the organizations (resulting in a limited information transparency in the supply chain), the participants choose the *compliance level* and the *round table structure* despite the cost savings achieved on a chain level by the process measures.

7.2. *The coffee distribution chain*

The coffee distribution chain comprises coffee bean growers, benefices (little companies which process the coffee beans), exporters and importers, coffee roasting plants, retailers and consumers. In general, the following environmental problems can be detected with the coffee growers: high usage of water, use of pesticides, and the use of manure causing problems with the ground water and surface water. The benefices have to deal with wastes like pulp, odor problems and the use of water in their process. The coffee roasting plants mainly cause odor problems, in addition to an overall energy problem concerning transportation. From a supply chain environmental perspective, the end-consumer creates the packaging problem (Nijhuis, Aardoom, & Wolters, 1996).

The participants of the coffee distribution chain were considering a market-oriented environmental care strategy to anticipate higher, environmental demands of end consumers and to obtain insight in expected cost saving effects. In line with this strategy, a market-oriented LCA was executed in which the already mentioned environmental effects were included. Detailed environmental information about each step of the coffee distribution chain was gathered.

The analysis resulted in a detailed description of the environmental problems throughout the chain and a list of potential measures to be taken. For example, the coffee roasting plant can become more technologically advanced, it can re-use pulp, implement more efficient transportation and clearing of waste water, new technologies can cut down on the water use, or more environment-friendly product packaging can be developed. To be able to develop and implement the measures, consulting structures were constructed. For instance, between the benefices and the growers for the re-use of pulp as manure. Another example is a consulting structure between benefices and local governmental authorities and chambers of commerce to stimulate knowledge transfer between benefices about appropriate environmental measures. Another consulting structure was developed between all actors in the chain (growers, benefices, importers, coffee roasters and retailers) to discuss and realize the logistics and the marketing of their, environmental-friendly product. In conclusion, in order to gather such detailed LCA data and implement the conclusions drawn from that information, a multi-focus network structure was required.

7.3. Linking types of LCA to the supply chain co-operation structures

On the basis of the theoretical description of chain co-operation structures we can conclude that as complexity and differentiation in consulting structures increase, tighter partnerships are required. The two cases illustrate this point of view. In the case of the coffee distribution chain, the actors have to be open, discuss and invest in each other to be able to reach the overall goal of marketing an environmentally-friendly coffee. The implementation of this goal puts high demands on the co-operation of supply chain partners. Of course, this is logical since more information is exchanged on processes and products, requiring an ever-more open and trustworthy co-operation model. It can even be the case in this form of co-operation that companies invest in other companies within the chain to improve the overall environmental performance, following the supply chain management line of thought. In the case of the slaughter by-product chain we saw that even though there were some possibilities of saving money through prevention measures (process-oriented LCA), no match was made between this type of LCA and the chain co-operation structure. The demands to the partnership to meet the process-oriented goal were to high for (some of) the partners; they choose for the compliance level of LCA and the round table co-operation structure. When we link these findings to the different types of LCA, we find the overview depicted in Fig. 4.

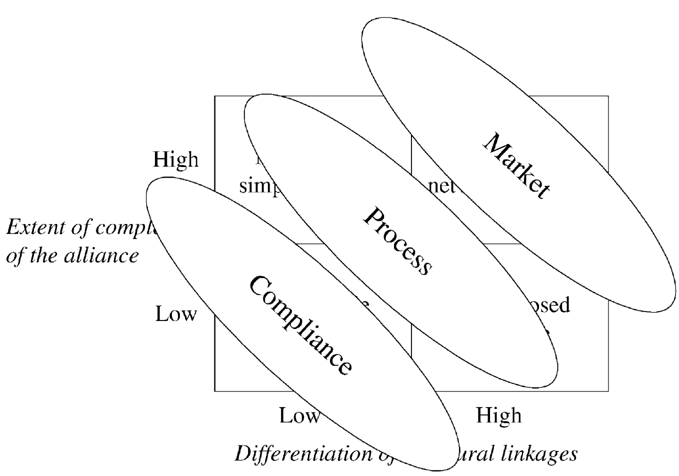

Fig. 4. Chain structures and types of LCA.

8. Conclusion

In this paper we stressed three primary points to guide the integration of LCA in supply chains. First, identifying the environmental care strategy of the chain is an important first step in choosing the type of LCA. This is critical for the managerial selection of information used in the LCA. Second, the requirements that have to be met to execute the LCA in the supply chain must be known. These requirements determine the feasibility of the execution of the LCA itself and the results of the LCA. An important managerial question that arises at this point is whether or not the planned environmental goals can be realized. Third, to ensure the execution of LCA and the implementation of the LCA-based goals of the environmental chain strategy, it is important to understand the relation between the type of LCA and the type of chain structure.

We draw the conclusion that if chains want to use LCA as a management instrument, they may have to adjust the chain structure to meet the requirements set for the use of that instrument. When the suitable chain structure is not realized, the results of the information gathering as well as the implementation of the LCA-based measures to reduce the environmental burden will not be successful.

Finally, we propose that the relation between the particular type of LCA and the chain structure is not static. After all, the choice of the type of LCA is conditioned by the choice of the environmental chain strategy. This strategy is influenced by factors outside the chain such as competition, governmental laws, consumer preferences and preferences of other stakeholders. The strategy is also influenced by chain-internal factors such as budget, knowledge, technology, co-operation, etc. In short, other more general analysis and choices have to be made which directly affect the choices concerning the environmental aspect of the supply chain. The integration of environmental care into the more general policy of chains should therefor boost the integration of LCA in supply chains.

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