UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ENGENHARIA CIVIL, ARQUITETURA E URBANISMO

Avaliação da Sustentabilidade na Gestão das Cadeias de Oferta de Bionergia

Assessment of Sustainability within Bioenergy Supply Chain Management

Alessandro Sanches Pereira

Campinas, SP
2012

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Tese de doutorado apresentada à Comissão de Pós-Graduação da Faculdade de Engenharia Civil da Universidade Estadual de Campinas, como parte dos requisitos para a obtenção do título de Doutor em Engenharia Civil, na área de concentração de Saneamento e Ambiente.

Orientadora: Prof. Dr. Emília Wanda Rutkowski

Campinas, SP
2012

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UNIVERSIDADE ESTADUAL DE CAMPINAS
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AVALIAÇÃO DA SUSTENTABILIDADE NA GESTÃO DAS CADEIAS DE OFERTA DE BIOENERGIA

ALESSANDRO SANCHES PEREIRA

Tese de Doutorado aprovada pela Banca Examinadora, constituída por:

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Resumo

A otimização do desempenho das cadeias de ofertas é um processo importante para promover o desenvolvimento sustentável, uma vez que as atividades de produção e seus fluxos de distribuição de produtos estão intimamente ligadas às mudanças ambientais. Neste contexto, o conceito gestão sustentável da cadeia de oferta é entendido como a gestão dos serviços, produtos e matérias-primas ao longo da cadeia com melhorias para os objetivos ambientais e sociais. Este estudo analisa a cadeia de oferta de biomassa florestal com a finalidade de propor uma estratégia de avaliação de desempenho. A Suécia foi usada como área de pesquisa e forneceu informação para a construção da estratégia para a avaliação do conceito de sustentabilidade no desempenho da cadeia de oferta. É importante abordar que este estudo é o resultado da parceria entre Brasil e Suécia representados pela UNICAMP, Universidade Estadual de Campinas, e KTH, Royal Institute of Technology, dentro do Programa de Cooperação Externa Erasmus Mundus entre a União Européia e Brasil.

Palavras-chave: *Desenvolvimento sustentável, gestão da cadeia de oferta, sistemas bioenergéticos.*

Abstract

The performance optimization of supply chains is an important process to promote sustainable development, since production activities and products distributions flows are closely linked to environmental changes. In this context, the sustainable supply chain management concept is understood as the management of services, products and raw materials along the chain with improvements to the environmental and social goals. This study analyzes the forest-based biomass supply chains with the purpose of proposing a performance assessment strategy. Sweden provided a framework that was used to design a strategy to guide supply chain performance evaluation. It is important to address that this study is the outcome of the partnership between Brazil and Sweden represented by UNICAMP, Universidade Estadual de Campinas, and KTH, Royal Institute of Technology, under the Erasmus Mundus External Cooperation Window EU-Brazil, StartUP Program.

Keywords: *sustainable development; supply chain management; bioenergy systems.*

Preface

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"WHAT LIES BEHIND US AND WHAT LIES AHEAD OF US ARE TINY MATTERS COMPARED TO WHAT LIVES WITHIN US."

HENRY DAVID THOREAU

Abbreviations and Nomenclature

BSC	Balanced Scorecard
BPR	Business Process Reengineering
CLM	Council of Logistics Management
CPM	Critical Path Method
CSCMP	Council of Supply Chain Management Professionals
EMS	Environmental Management System
EU	European Union
DfE	Design for the Environment
DK	Denmark
GHG	Greenhouse gases
IE	Industrial Ecology Theory
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MIT	Massachusetts Institute of Technology
MRP	Material Requirements Planning
MRPII	Manufacturing Resource Planning

NCPDM	National Council of Physical Distribution Management
OECD	Organisation for Economic Co-operation and Development
OHSAS	Occupational Health and Safety Advisory Services
P2	Pollution Prevention
PAS	Performance Assessment Strategy
PERT	Program Evaluation and Review Technique
PSS	Product Service System
RES	European Renewable Directive
Rio92	United Nations Conference on Environment and Development
Rio+10	World Summit on Sustainable Development
SCOR	Supply Chain Operations Reference
SD	Sustainable Development
TQM	Total Quality Management
UK	United Kingdom
UN	United Nations Organization
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America
WBCSD	World Business Council for Sustainable Development
WTO	World Trade Organization

Sumário

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1 Executive Summary in Portuguese

This chapter presents the translation into Portuguese of the introduction and conclusion sections of the thesis. The introduction provides background information, defines the objective of the thesis, research question, methodology, its scope and limitations. It also underlines the organization of the study. The conclusion presents the thesis' final outcome by placing the analysis into perspective and answering the research question. It also provides potential steps for future research developments.

1.1 Introdução

O mundo nunca esteve tão conectado quanto nos dias atuais, a globalização conecta o mundo todo a tudo. Esta interconexão nos torna completamente dependentes de fluxos e redes cada vez mais complexas e envoltas em relações no tempo e no espaço, sejam elas econômicas, políticas, culturais, logísticas ou ambientais. Nas últimas décadas, ocorreram mudanças significativas em todas as dimensões da sociedade. De um lado, o desenvolvimento exponencial da ciência e tecnologia, garantindo à sociedade tanto o aumento da expectativa de vida como a capacidade de autoaniquilação. Por outro, há a crescente demanda da utilização de matéria e energia para atender novas e crescentes necessidades sociais. Este momento que vivemos não tem precedentes na história mundial, as mudanças em curso estão condensadas em poucas décadas e têm escopo global. Pela primeira vez o fluxo da atividade humana é tão extensivo que produz mudanças ambientais em escala global (HOBSBAWM, 1995).

Focando apenas na demanda energética, é desnecessário destacar que a sociedade ainda é dependente dos fluxos de combustíveis fósseis para suprir sua crescente demanda de energia. O atual consumo global de energia quase dobrou nos últimos 36 anos e continua crescendo rapidamente, ganhando proporção maior que a estimada (INTERNATIONAL ENERGY AGENCY, 2011). Como resultado, estamos enfrentando uma nova crise baseada no esgotamento de recursos, escassez prevista de combustíveis fósseis, aumento dos preços da energia em todo o mundo e intensificação da competição global por recursos energéticos. Neste contexto, as questões de segurança energética tornaram-se tema recorrente na agenda internacional. No entanto, preocupações ambientais também foram levantadas devido à sua conexão direta com as práticas de geração de energia.

Historicamente, a atmosfera tem sido o principal repositório para os poluentes. Emissões de várias fontes ainda são liberadas e consideradas uma solução prática e econômica. Como resultado desta diluição atmosférica de poluentes, problemas antes assumidos como locais ganham novas dimensões e perdem as fronteiras. Vários desses problemas ambientais têm sido atenuados pelo desenvolvimento de políticas e adoção incremental de tecnologias limpas. No entanto, problemas relacionados diretamente com a mudança do clima têm crescido, e metas de redução de emissões dos gases causadores de efeito estufa (GEE) nunca foram cumpridas (GEELS, HEKKERT e JACOBSSON, 2008).

A necessidade de mudança do atual modelo de sistemas energéticos para fontes renováveis é reconhecida. Segundo a Agência Internacional de Energia, fontes de energia renováveis - eólica, solar, hidrelétrica e biomassa, responderam por apenas 13% da oferta mundial de energia primária e 19% da produção mundial de eletricidade em 2009. Apesar da lenta recuperação da economia mundial, as emissões de GEE atingiram uma nova alta (INTERNATIONAL ENERGY AGENCY, 2011). A agência calcula que, sem o estabelecimento de novas políticas e tecnologias limpas, a demanda mundial de energia primária poderá aumentar em 45% até 2030 em comparação aos níveis de 2006. A agência enfatiza ainda a necessidade de ações inovadoras, a fim de mudar o chamado *"business-as-usual"* e fomentar uma participação maior das fontes de energias renováveis nas opções energéticas do futuro global (INTERNATIONAL ENERGY AGENCY, 2010).

A busca pelas fontes de energia renovável não é novidade, o choque nos preços de energia na década de 1970 serviu como um importante incentivo para rever as práticas energéticas. Como resultado, várias nações lançaram programas de eficiência e tentaram desenvolver soluções locais para substituir os combustíveis fósseis. Um exemplo é o reconhecido programa brasileiro de etanol, que fez a mistura de etanol à gasolina obrigatório no país desde 1976 (PACINI e SILVEIRA, 2011). No entanto, os baixos preços do petróleo têm sido uma barreira que impede a energia renovável de ocupar uma posição mais significativa na escala comercial mundial.

Recentemente, as fontes de energia renovável ganharam novo impulso como resultado de políticas favoráveis ao seu uso. Um exemplo é a agenda política da União Européia (UE), cuja meta é atingir 20% de energias renováveis em sua matriz energética até 2020. No entanto, o desenvolvimento de energias renováveis não é uma tarefa fácil. A crescente disponibilidade de gás natural e a remoção tardia de subsídios aos combustíveis fósseis podem voltar a prejudicar a competitividade das fontes de energia renovável (SANCHES-PEREIRA, 2011).

Em abril de 2009, a UE aprovou uma nova diretiva que visa promover a utilização de energia proveniente de fontes renováveis. A diretiva estabelece uma visão comum para a região, onde cada Estado membro tem de atingir uma meta específica, para que a União tenha no final 20% da sua matriz energética baseada em fontes renováveis até o ano de 2020. A diretiva também contém um roteiro para reduzir 20% das emissões totais de GEE no mesmo período e define um plano estratégico para o desenvolvimento e implementação de tecnologias (SET-Plan) para reduzir a dependência de petróleo na UE (EUROPEAN UNION, 2009). Neste contexto, a energia renovável está assumindo uma importância crescente entre os Estados membros, principalmente motivada pela segurança de abastecimento, bem como pelos objetivos de redução de emissões de GEE.

Entre os países membros, a Suécia é muitas vezes considerada como uma das nações pioneiras no desenvolvimento, promoção e implementação de políticas de energia renovável e incentivo tecnológico. Seguindo o modelo sueco, a utilização da biomassa tem aumentado na UE e, especialmente, a biomassa de origem florestal. Cerca de 75% da biomassa utilizada na Europa como fonte de energia renovável é proveniente de florestas na forma de resíduos. Menos de 2% da biomassa são provenientes de culturas energéticas e na forma de resíduos agrícolas. Os 23% restantes consistem principalmente de resíduos sólidos urbanos e, parcialmente, de esgoto, esterco e madeira recuperada (EUROPEAN CLIMATE FOUNDATION, 2010).

É importante ressaltar que a diretiva não é a única força motriz que afeta diretamente a expansão da bioenergia na Europa. Ling e Silveira (2005) consideram que as políticas atuais que estão sendo aplicadas na UE melhoraram a condição para o aumento de geração e consumo de bioenergia, mas também existem outras forças importantes, como a internacionalização do segmento de bioenergia, integração de sistemas de bioenergia com outros processos de transformação, além da bioenergia estar se tornando uma das principais alternativas renováveis (LING e SILVEIRA, 2005). Portanto, biomassa se transformou em uma fonte de energia confiável para grande geração de calor, eletricidade e combustível. Além disso, a biomassa – principalmente a proveniente da madeira, irá continuar a desempenhar um papel fundamental no cumprimento da quota de 20% de energias renováveis utilizadas na Europa. Porém, a percepção corrente entre importantes agentes é que os alvos estabelecidos pela UE só serão possíveis através do aumento da extração de biomassa florestal. Este aumento de extração para fins energéticos poderá ter impactos negativos não apenas sobre outros segmentos do setor florestal, mas também sobre o setor florestal como um todo (WERHAHN-MEES, PALOSUO, *et al.*, 2010;. SANCHES-PEREIRA, 2011).

Este estudo analisa a cadeia de oferta de biomassa florestal e tem como finalidade propor uma estratégia de gestão para a avaliação de desempenho desta mesma cadeia. O estudo dá especial atenção às cadeias de abastecimento de bioenergia sueca. Seu escopo foca na cadeia sueca de oferta de biomassa florestal, a qual serviu de base para a concepção da estratégia para a avaliação da performance na gestão das cadeias sustentáveis de oferta.

A estratégia proposta é um instrumento útil para a tomada de decisão e ele pode ser utilizado por uma variedade de agentes. Como resultado, a estratégia pode ajudar tanto na tomada de decisões pontuais dentro do sistema de geração de bioenergia quanto na tomada de decisões políticas para compreender os riscos e vulnerabilidade da cadeia de oferta de biomassa florestal para a geração de energia. É importante abordar que este estudo é o resultado da parceria entre os governos do Brasil e da Suécia, representados respectivamente pela UNICAMP, Universidade Estadual de Campinas, e KTH, Instituto Real de Tecnologia, dentro do programa de cooperação externa Erasmus Mundus entre a União Européia e o Brasil.

Objetivos

O objetivo geral desta pesquisa é avaliar a sustentabilidade na gestão das cadeias de oferta e indicar uma estratégia que possa orientar a avaliação de desempenho. O estudo dá especial atenção às cadeias de abastecimento de bioenergia. Além disso, fornece a compreensão sobre as necessidades específicas dos sistemas de bioenergia sueca, que são caracterizadas por condições locais específicas. Neste contexto, esta pesquisa busca responder à seguinte questão acadêmica: *Como agentes tomadores de decisão podem expandir os limites do gerenciamento da cadeia de oferta a fim de aumentar sua sustentabilidade?*

Para atingir ao objetivo geral da pesquisa foram estabelecidos os seguintes objetivos específicos:

- Definir um quadro teórico para a cadeia de oferta sustentável
- Definir a estrutura do sistema bioenergético
- Compreender a dinâmica da cadeia de oferta de biomassa florestal
- Desenvolver uma estratégia para avaliação de desempenho de cadeias de oferta de bioenergia

Passos metodológicos

A pesquisa tem como ponto de partida o fato de que a sustentabilidade não poder ser resumida na forma de leis ou generalizações desvinculadas de contexto e tempo. Isto é, o conceito envolve a questão temporal, uma vez que a sustentabilidade de um sistema só pode ser observada a partir da perspectiva futura e dificilmente é possível verificar sua real sustentabilidade no contexto dos acontecimentos (BOSSEL, 1998).

Seguindo esta lógica, fica claro o forte dinamismo do conceito da sustentabilidade e, por esse motivo, a pesquisa não está fundamentada em uma única grande teoria, mas reconhece e entende que foi inevitável a ocorrência numerosa e contínua de incursões em teorias, na medida em que certos temas e questões se destacarem no decorrer das observações e análises.

Para cumprir o objetivo desta tese, duas categorias de métodos de pesquisa foram utilizados: revisão literária e análise de conteúdo, a fim de identificar diferenças e inter-relações relacionadas com o desenvolvimento do conceito de sustentabilidade e gestão de cadeia de oferta de biomassa florestal na Suécia.

O raciocínio indutivo foi aplicado para orientar a fase de concepção da estratégia. O ponto de partida foi a percepção corrente entre os principais agentes de mercado da indústria florestal européia, que acreditam que as metas de expansão da bioenergia estabelecidas pela UE são insustentáveis e o seu cumprimento só será possível através do aumento da extração de biomassa florestal. Durante esta fase de concepção, dados secundários foram coletados através da literatura, documentos oficiais, sítios eletrônicos governamentais e institucionais de autoridades européias e suecas.

A análise de conteúdo foi escolhida como método para o fornecimento de informações para o raciocínio indutivo. Trata-se de um método sistemático e confiável para o estudo de dados secundários (KRIPPENDORFF, 2004). Além disso, a análise de conteúdo pode ser usada como um instrumento para determinar as idéias-chave e temas centrais em publicações e medir as posições de agentes e suas tendências em processos de comunicação impressa (GUTHRIE, PETTY, *et al.*, 2004). Este método garantiu a possibilidade de investigar os pressupostos implícitos – tais como, o aumento da extração de biomassa florestal é insustentável – conjuntamente com declarações explícitas – o valor da meta obrigatória de expansão de bioenergia (GUTHRIE, PETTY, *et al.*, 2004;. KRIPPENDORFF, 2004).

Limites da pesquisa

Esta tese considera o caso específico do setor bioenergético sueco. O escopo consiste no sistema de geração de bioenergia, que inclui os aspectos técnicos de geração de bioenergia, ou seja, tecnologias de conversão e tipos de recursos de biomassa e aspectos globais de desenvolvimento do setor bioenergético tais como, quadros políticos, capacidades institucionais, infraestrutura e redes de agentes. Embora o estudo seja limitado ao contexto sueco e com base na análise de sites específicos europeus, o resultado desta pesquisa e os passos metodológicos escolhidos durante a investigação podem ser usados como modelo de análise para futuros estudos sobre o gerenciamento da cadeia de oferta relacionada.

Estrutura de apresentação

Esta tese foi escrita em inglês e está dividida em seis capítulos descritos abaixo.

O capítulo 1 apresenta a tradução em português da introdução e conclusão da tese de doutorado apresentada à Comissão de Pós-Graduação da Faculdade de Engenharia Civil da Universidade Estadual de Campinas.

O capítulo 2 introduz o tema da pesquisa. Ele fornece informações contextuais, define o objetivo geral, metodologia utilizada e as limitações do trabalho. Também destaca a organização do estudo e sua estrutura de apresentação.

O capítulo 3 apresenta conceitos básicos relacionados à sustentabilidade e gestão da cadeia de abastecimento. Ele também apresenta o quadro teórico para as cadeias sustentáveis de oferta e define o papel da ecologia industrial como um elo entre os aspectos de sustentabilidade dos processos industriais e a gestão da cadeia de oferta.

O capítulo 4 é baseado principalmente em observações do sistema bioenergético sueco e sua dinâmica. A pesquisa tem a Suécia como escopo, o qual é utilizado para definir o campo de estudo para a análise da gestão da cadeia de oferta de biomassa florestal. Também discute o papel da biomassa como recurso crítico para a expansão das fontes de energias renováveis.

O Capítulo 5 apresenta a estratégia de avaliação de desempenho (PAS), que pode ser aplicada tanto em empresas como em redes mais complexas, por exemplo, um setor produtivo. Este capítulo final coloca o trabalho em perspectiva e responde a questão levantada no estágio inicial da pesquisa sobre a possibilidade ou não de agentes tomadores de decisões serem capazes de expandir os limites do gerenciamento da cadeia de oferta, a fim de melhorar seu desempenho e aumentar sua sustentabilidade. Também fornece recomendações para o desenvolvimento de pesquisas futuras.

1.2 Conclusão

Este trabalho apresenta como conclusão a importância das cadeias de oferta como um importante componente estratégico para intervir no atual modelo de desenvolvimento e promover a implementação do desenvolvimento sustentável. Uma vez que as cadeias de oferta são importantes fatores das relações causais entre atividades humanas – produção e consumo – e mudanças ambientais. Desta forma, para uma cadeia de oferta tornar-se sustentável significa que a sua gestão deve levar em conta não apenas a eficiência econômica, mas também a justiça social e a limitação biofísica do processo de produção e consumo.

A fim de promover a sustentabilidade nas cadeias de oferta é necessário não só operacionalizar o conceito de sustentabilidade dentro do desempenho das redes, mas também ser capaz de verificar este mesmo desempenho nas práticas cotidianas. Por isso, é necessário traduzir realidades complexas de desempenho em uma sequência limitada de símbolos familiares ou referências bem definidas, tais como *confiabilidade, responsabilidade, agilidade, ativos* e *custo*, que são categorias de parâmetros comuns à prática da gestão de cadeias de oferta. Além disso, a avaliação de desempenho tem um papel mais substancial do que apenas a quantificação e contabilidade de ações, especialmente quando se trata de avaliar o desempenho das cadeias de oferta para a bioenergia. Neste caso, é necessário não só mobilizar recursos adicionais de biomassa para a expansão do sistema bioenergético, mas também evitar ou reduzir os impactos negativos dessa mesma expansão.

A estratégia proposta para a avaliação de desempenho (PAS) apresenta uma forte estrutura teórica e potencial para muitas aplicações, uma vez que ela oferece a oportunidade de ser usada de maneira muito diversificada. PAS pode ser utilizada não só em nível de gestão local (por exemplo, uma única empresa), mas também em redes mais complexas, tais como um grupo empresarial, organização de um segmento industrial ou de um setor produtivo inteiro. Ao utilizar uma perspectiva mais ampliada – economia ambiental ou ecológica – e alinhada com o conceito de sustentabilidade no lugar da economia neoclássica como meta de desempenho, a estratégia proposta torna-se um instrumento eficaz para a compreensão não só da rede e seus fluxos, mas também de suas fraquezas e pontos fortes. Como resultado, a PAS é um instrumento útil para os processos de tomada de decisão.

Neste contexto, esta pesquisa iniciou-se com a intenção de buscar uma resposta para a seguinte questão acadêmica: *Como agentes tomadores de decisão podem expandir os limites do gerenciamento da cadeia de oferta a fim de aumentar sua sustentabilidade?*

Um passo próximo, a solução é criar ferramentas de avaliação capazes de medir a sustentabilidade nas práticas cotidianas e traduzir dados sobre as condições e tendências do desenvolvimento sustentável dentro da rede em informação confiável e clara. Dentro desta perspectiva, a PAS amplia os limites da compreensão da gestão da cadeia de oferta e apresenta um método inteiramente novo ao combinar os elementos recorrentes na prática de gestão de uma forma padrão nova e distinta. No entanto, é importante verificar se a PAS tem potencial teórico para intervir no atual modelo e se é capaz de melhorar seu desempenho em busca da sustentabilidade.

Meadows (1999) afirma que a generalização de sistemas complexos é, por definição, perigosa. Como resultado, criar estratégias capazes de encontrar pontos de alavancagem operacional ou locais adequados para intervir em um sistema não pode ser um processo intuitivo, porque eles não são facilmente acessíveis. Seu trabalho também confirma que existe uma relação diretamente proporcional entre a eficácia dos pontos de alavancagem operacional e a resistência dos sistemas em aceitar suas influências. Quanto maior a influência dos pontos de alavancagem, maior é a capacidade dos sistemas em resistir às influências para mudar os padrões (MEADOWS, 1999). São 12 pontos de alavancagem operacional:

Parâmetros: eles são descritos como os pontos de menor efeito na alavancagem operacional de um sistema, no entanto, são os pontos mais facilmente percebidos entre todos os outros. Parâmetros raramente mudam o comportamento ou têm efeito a longo prazo. Por outro lado, eles podem fornecer uma descrição instantânea da situação. A estratégia proposta não só reorganiza parâmetros comumente utilizados em práticas de gerenciamento, como os classifica como iniciativas reativas ou pró-ativas, a fim de fornecer uma visão mais estratégica da performance. PAS atende este ponto de alavancagem operacional.

Tamanho do estoque: estoques operaram como amortecedores e apresentam a função de reguladores sistêmicos. Portando, quando o tamanho do estoque é maior que a quantidade de ações relacionadas com os fluxos de entradas e saídas potenciais, ele mantém a estabilidade do sistema. A estratégia proposta considera o tamanho do estoque em todas as etapas da avaliação da performance, tanto na dimensão operacional como na dimensão estratégica do gerenciamento da cadeia de oferta. PAS atende este ponto de alavancagem operacional.

Estrutura: este ponto de alavancagem operacional está relacionada com a forma como a rede de agentes ou elementos é organizada dentro do sistema. Ele apresenta um enorme impacto sobre as operações sistêmicas. Mudanças estruturais são difíceis e, muitas vezes, são monetariamente proibitivas. Compreender a estrutura pode definir as limitações operacionais e "gargalos" no sistema. Um dos principais objetivos da estratégia proposta é mapear as limitações operacionais e identificar gargalos na estrutura da rede. PAS atende este ponto de alavancagem operacional.

Taxa de oscilação sistêmica: a principal causa de oscilações em um sistema diz respeito ao atraso tempo entre ação e resposta. Isto significa que informação é um elemento importante para manter ou intervir em um sistema. Informação recebida muito rápida ou muito tardiamente podem causar reações positivas ou negativas e gerar oscilações sistêmicas. A estratégia tem como um dos seus componentes medir, por exemplo, o tempo necessário para o preço de uma mercadoria se adaptar a um desequilíbrio entre oferta e demanda. PAS atende este ponto de alavancagem operacional.

Fortalecimento de retornos negativos: este ponto de alavancagem representa a capacidade de um sistema para manter seu estoque em/ou próximo ao equilíbrio. Um retorno negativo é uma forma de autocorreção sistêmica. Desta forma, ele depende da precisão do monitoramento, da velocidade de reação e do poder de resposta para regular a dinâmica do sistema. Os parâmetros, mencionados anteriormente, são importantes elementos para compreender o sentido e o tamanho das medidas corretivas. A estratégia proposta pode ajudar a identificá-los dentro da rede. Por exemplo, PAS facilita o reconhecimento da variação de preços e seus efeitos em manter o equilíbrio entre oferta e demanda. Quanto mais informações entre produtores e consumidores sobre o custo real do produto final, mais eficiente e clara é a performance da cadeia de oferta PAS atende este ponto de alavancagem operacional.

Direcionamento de retornos positivos: o retorno positivo é uma forma de autorreforço. Isto significa que quanto mais recorrente o retorno se torna, maior sua força e influências serão em seu próximo retorno. Assim, retornos positivos são fontes de crescimento, expansão e colapso de um sistema. Retardar ou dirigir seu impulso é, geralmente, um ponto de alavancagem poderoso. Por exemplo, a erosão do solo causada pela alta demanda de madeira. Quanto maior o consumo de biomassa florestal, menor é a área coberta por vegetação capaz de amenizar a força de chuvas e reduzir o carregamento de solo. A estratégia proposta facilita a identificação destes retornos. PAS atende este ponto de alavancagem operacional.

Rede de informação: o acesso à informação pode ser considerado uma intervenção poderosa e a construção de uma rede de informação, na maioria das vezes, é uma solução mais fácil e barata do que construção ou adaptação de uma infraestrutura física. A estratégia proposta mapeia o fluxo de informação e identifica também, além de sinergias e antagonismos, a falta de informação. PAS atende este ponto de alavancagem operacional.

Regras do sistema: as regras de um sistema definem seus limites e a dinâmica de seus agentes. A estratégia proposta busca identificar todos estes componentes uma vez que o desempenho de uma cadeia de oferta é diretamente afetada pelo desempenho de todos os componentes presentes em sua estrutura e pela sua capacidade em responder a mudanças e seguir regras. PAS atende este ponto de alavancagem operacional.

Autorreorganização: este ponto de alavancagem está relacionado à mudança ou reorganização de qualquer um dos aspectos listados anteriormente. A autorreorganização significa também a capacidade do sistema adicionar novas estruturas físicas, criar instituições, acrescentar novos retornos negativos ou positivos, e gerar novas regras. Desta forma, ela está relacionada à resiliência sistêmica. A estratégia proposta pode mapear combinação da rede em diferentes cenários, mas não pode prever como estas novas estruturas serão auto-organizadas dentro do sistema. PAS atende parcialmente este ponto de alavancagem operacional.

Metas: os objetivos de qualquer sistema são sobrevivência, resistência, evolução, diferenciação, etc. Este é um ponto de alavancagem considerado superior aos outros porque tudo mencionado anteriormente é moldado para atingir esses objetivos. Portanto, este ponto de alavancagem acaba também moldando a estratégia proposta uma vez que ela só pode avaliar o desempenho em relação aos objetivos do sistema. PAS atende parcialmente este ponto de alavancagem operacional.

Mentalidade: Sociedade define idéias e as compartilha entre seus membros. A estratégia proposta pode fornecer um retrato instantâneo do paradigma e apontar suas anomalias e falhas. PAS atende parcialmente este ponto de alavancagem operacional.

Mudança de Paradigma: este é o ponto mais alto de alavancagem, pois ao perceber que o paradigma é limitado pode-se escolher qualquer outro modelo e alterar por completo o sistema. PAS não atende este ponto de alavancagem operacional.

Embora a estratégia de avaliação proposta apresenta um potencial teórico para intervir em sistemas complexos e empurrar os seus limites, é importante abordar que a eficácia da PAS é guiada pela perspectiva escolhida para definir o desempenho da cadeia de oferta. A escolha da perspectiva baseada na economia neoclássica em detrimento das perspectivas baseadas na economia ambiental ou economia ecológica não só pode alterar o grau de alavancagem cobertos por Meadows (1999), mas também reorganizar o status destes pontos de *"cobertos"* para *"não cobertos"* pela estratégia. Esta flexibilidade de escolha entre as perspectivas proporciona versatilidade para a estratégia e ratifica sua característica holística, porém permite ser mal utilizada e justificar o *"business as usual"* como a melhor abordagem no lugar de iniciativas sustentáveis.

Pesquisas futuras

A continuação da investigação é necessária para validar a aplicabilidade do PAS no contexto da vida real. A continuidade da pesquisa acontecerá por meio de estudos de casos, uma vez que eles podem fornecer fortes evidências para apoiar não só a validade técnica, mas também a confiabilidade como estratégia de gestão (YIN, 2009). A idéia é realizar três estudos de caso. O primeiro será realizado na

Suécia, o segundo no Brasil e o terceiro em um país Africano a ser determinado. A idéia por trás da utilização de três estudos de caso distintos é sincronizar os processos de avaliação e de validação da estratégia em diferentes contextos. Embora este método possa simplificar demais os problemas, ele constrói conhecimento e valida as informações recolhidas através de evidências fornecidas por uma grande variedade de fontes (STAKE, 1995; SIMONS, 2009).

Esta futura pesquisa será desenvolvida na Divisão de Energia e Estudos Climáticos, Departamento de Tecnologia Energética, da Faculdade de Engenharia Industrial e Gestão dentro do programa de pós-graduação em Planejamento Energético no KTH Royal Institute of Technology, na Suécia.

2 Introduction

"There is nothing more difficult … than to take the lead in introducing a new order of things."
Nicollo Machiavelli, The Prince.

The age we live is unprecedented in world's history. In recent decades, significant changes occurred in all dimensions of society. On the one hand, an exponential development of science and technology ensures not only an increased life expectancy but also the ability to self-annihilation. On the other hand, an increasing resources and energy demand for meeting new and fast growing societal needs is the basis for development. These current changes are condensed in a few decades and have global scope and, for the first time in history, the flows of human activities are so extensive that produce environmental changes on a global scale (HOBSBAWM, 1995).

Translating this context into an energy systems' perspective, it is needless to highlight that society is still relying on fossil fuel flows to supply its increasing energy demand. In fact, the current global final energy consumption has almost doubled in the last 36 years and it is growing rapidly and getting even larger (INTERNATIONAL ENERGY AGENCY, 2011). As a result, we are facing a new crisis based on resource depletion, expected scarcity of fossil fuels, increasing energy prices worldwide, and intensification of global competition for energy resources. Clearly, energy security matters became recurrent topic on the international agenda. However, environmental concerns have also been raised due to their direct connection to energy generation practices. Historically, the atmosphere has been the main pollutant repository. Emissions from various sources are still being released and considered a simpler and cheaper solution. As a result of atmospheric dilution of pollutants, problems before assumed as local have scaled up and lost the borders. Several of these environmental problems have been mitigated by policies' development and incremental adoption of clean technologies. However, problems such as climate change have grown worse and greenhouse gases (GHG) emissions reduction targets have never been met (GEELS, HEKKERT e JACOBSSON, 2008).

The need to shift energy systems towards renewable sources is well recognized. According to the International Energy Agency (IEA), renewable energy sources – such as wind power, solar energy, hydropower and biomass – responded for only 13% of the global primary energy supply and 19% of the global electricity production in 2009. Despite the slow recovery in the world economy, GHG emissions reached a new high (INTERNATIONAL ENERGY AGENCY, 2011). IEA calculates that, without new policies and clean technology in place, global primary energy demand could increase by 45% by 2030 compared to 2006 levels. The agency emphasizes the need for innovative actions in order to change the so-called "business-as-usual" scenario and foster an increased share of renewables in the future global energy mix (INTERNATIONAL ENERGY AGENCY, 2010).

Renewable energy is no novelty, the energy price shocks of the 1970s served as a major incentive to revisit energy practices. As a result, several nations launched efficiency programs and tried to develop solutions to replace fossil fuels. One recognized example is the Brazilian ethanol program, which made the mixture of ethanol with gasoline mandatory in the country since 1976 (PACINI e SILVEIRA, 2011). However, for some time low oil prices have been a barrier preventing renewable energy from taking up on large commercial scale worldwide. More recently, renewables gained new momentum as a result of favorable policies, such as in the European Union (EU) where the target is to reach 20% of renewables by 2020. Nevertheless, the development of renewables is by no means given. The increasing availability of gas and the delayed removal of fossil fuel subsidies could again hamper the competitiveness of renewables for many years to come (SANCHES-PEREIRA, 2011).

In April 2009, the EU adopted a new renewable directive (RES), which aims to promote the use of energy from renewable sources. The Directive sets a common vision for the region; each member state has to achieve a specific target so that, as a whole, the Union shall have 20% of the total energy based on renewables by the year 2020. It also contains a roadmap to cut down 20% of the total GHG emissions in the same period and sets an important framework alongside with the European Strategic Energy Technology Plan (SET-Plan) for reducing the EU's oil dependence (EUROPEAN UNION, 2009). In this context, renewable energy is assuming an increased prominence among member states, mostly motivated by security of supply as well as GHG emissions reduction objectives. Among the member countries, Sweden is often regarded as one of the frontrunners concerning the development, promotion and implementation of renewable energy policy and technology.

Following this path, the use of biomass has increased steadily in the EU, especially when it comes to forest-based biomass. Around 75% of the biomass used in Europe as energy source comes from forests. The biomass used for energy can be derived directly from forestry activities in the form of wood fuel or forest residues, and indirectly from industrial processes as sawdust or black liquor. Agricultural residues and energy crops account for less than 2% of the bioenergy used in the EU. The remaining 23% consists mostly of municipal solid waste, in the form of sewage, manure and recovered (EUROPEAN CLIMATE FOUNDATION, 2010). The RES directive is not the only driving force affecting bioenergy utilization. However, other forces also exist that are influencing the increased utilization of bioenergy. Ling and Silveira (2005) consider that policies being applied in the EU improve conditions for bioenergy markets but other important forces such as internationalization of the bioenergy segment, integration of bioenergy systems with other transformation processes, and the fact that bioenergy is a recognized and reliable energy alternative to become a mainstream alternative (LING e SILVEIRA, 2005). Furthermore, increasing competition in biomass-based segments of the industry also creates a pressure and forces innovation towards improved efficiency. In this context, bioenergy has an important complementary role to play.

In fact, biomass is not just an alternative but has turned into a major reliable energy source for heat, electricity generation and fuel in the transport sector. In addition, biomass – especially wood – is expected to continue playing a key role in the share of renewables used in Europe. Meanwhile, the current perception among some market actors is that meeting bioenergy targets set by EU will only be possible by increasing the biomass extraction from forest. However, increasing extraction of forest biomass for energy purposes could have impacts on other segments of the forestry sector as a whole (WERHAHN-MEES, PALOSUO, *et al.*, 2010; SANCHES-PEREIRA, 2011). Thus, a better understanding of the interplay among forest-based industries and their supply chains is needed to guarantee the development of bioenergy without harming other important industries.

This study analyzes the forest-based biomass supply chains with the purpose of proposing a performance assessment strategy. The Swedish forest-based bioenergy supply chain to guide our supply chain performance evaluation and to design the proposed strategy. The proposed strategy is a useful instrument for decision-making and it can be used by a variety of stakeholders, from management staff to policymakers. As a result, the strategy can assist small actors and their punctual decisions in the bioenergy system and also help policymakers to understand the risks and vulnerability of the bioenergy supply chain. It is important to address that this study is the outcome of the partnership between Brazil and Sweden represented by UNICAMP, Universidade Estadual de Campinas, and KTH, Royal Institute of Technology, under the Erasmus Mundus External Cooperation Window EU-Brazil, StartUP Program. The program is an institution-based mobility and scholarship project organized by a consortium of some the most prestigious universities in Europe and Brazil. The funding from the European Commission has allowed me to conduct the final stage of my research in Sweden.

2.1 Research question and objectives

The ultimate objective of this research is to indicate a strategy to guide supply chain performance evaluation. The study gives particular attention to bioenergy supply chains. In addition, it provides understanding on the specific needs of the Swedish bioenergy systems, which are characterized by relevant local conditions. In order to do so, a research question was formulated: *How can decision-makers push the boundaries of supply chain management in order to enhance its sustainability?*

In pursuing an answer for the research question, four objectives were formulated:

1. To define a framework for sustainable supply chain
2. To define an illustrative system
3. To understand the supply chain dynamics
4. To develop a performance assessment strategy for bioenergy supply chains

2.2 Methodological steps

In order to fulfill the objective of this thesis, various research steps were utilized and a number of different information sources have been explored. The study was processed with two categories of research methods: literature review and content analysis in order to identify drivers and influences related to bioenergy supply chain, using Sweden as an example.

During the designing phase of the performance strategy, different types of secondary data and information were collected. The main sources of data were published articles, reports and documents by various authors, website information of organizations, companies, and governmental authorities, and statistic data from the Internet, statistic institutes webpage, and European and Swedish authorities.

Inductive reasoning was used to guide the design phase. The starting point was the current perception among important market actors in the forestry industry, who believe meeting bioenergy targets set by EU is unsustainable and it will only be possible by increasing the biomass extraction from forest. Content analysis was chosen as a method for feeding information to the inductive reasoning. It offered the possibility to investigate implicit assumptions (i.e., increasing the biomass extraction from forest is unsustainable) alongside explicit statements (i.e., meeting bioenergy targets) (GUTHRIE, PETTY, *et al.*, 2004; KRIPPENDORFF, 2004). Content analysis was chosen because it is a systematic and reliable method for studying published information (e.g., secondary data) (KRIPPENDORFF, 2004). Furthermore, content analysis can be used as an instrument for determining key ideas and themes in publications but also for measuring comparative positions and trends in reporting processes (GUTHRIE, PETTY, *et al.*, 2004).

2.3 Scope and limitations

This thesis considers the specific case of the Swedish bioenergy sector. The scope consists of the bioenergy system, which comprises both the technical aspects of bioenergy generation (i.e., conversion technologies and biomass resources types) and overarching aspects of bioenergy development (i.e., policy frameworks, institutional capacities, infrastructure and actors' networks). Although the study is limited to the Swedish context and based on site specific analysis, the thesis outcome and methodological steps taken during the research can be used as a baseline and/or analytical model for further supply chain management studies related to different product and service chains.

2.4 Organization of the thesis

The thesis is divided into five chapters, which are described below.

Chapter 1 presents the translation into Portuguese of the introduction and conclusion sections of the thesis. Chapter 2 introduces the research topic and the study as a whole. It provides background information, defines the objective of the thesis, research question, methodology, its scope and limitations. It also underlines the organization of the study. Chapter 3 presents concepts related to sustainability and supply chain management. It also presents the theoretical framework for sustainable supply chains and defines the role of industrial ecology as a link between sustainability aspects of industrial processes and supply chain management. Chapter 4 is mainly based on observations of the Swedish bioenergy systems and its supply chain dynamics. It uses Sweden as a framework to set a baseline and/or analytical model for the supply chain management analysis. It also discusses the role of biomass as a critical resource for renewable energy expansion and the need of a well-organized and functioning biomass supply chains. Finally, chapter 5 presents the Performance Assessment Strategy (PAS), which can be applied at a variety of levels from a single company standpoint to more complex networks such as an organization group, an industrial segment or a productive sector. It also presents the conclusion by placing the analysis into perspective and answering the research question.

3 Sustainability and supply chain management

This chapter covers objective 1. It presents the theoretical framework for sustainable supply chains. It discusses the basic concepts concerning sustainability and supply chain management. It defines the role of industrial ecology to illustrate the connection between sustainability aspects of industrial processes and supply chain management. This chapter is also the result of the literature review conducted during the research.

Environmental problems faced by modern society are no novelty; mankind has just recently been able to understand the complexity and interdependency of various factors. The more we learn, the more we find that current environmental problems are not isolated events that can be easily understood. The factors involved that shape the environmental problems are systemic, interlinked and interdependent (CAPRA, 2004). At this moment in time, there is no precedent in history, nor is there an ultimate answer or consensus for solution of environmental problems (MORIN, 2001). For the first time, economic activity across the world is extraordinarily extensive. Its velocity generates environmental changes on a global scale. As a result, rapid degradation of environmental quality is occurring before our eyes. The environmental changes in progress today have developed in just a few decades, and now the impacts are being felt worldwide. To enable change of this scenario requires broad perspectives and actions (SANCHES-PEREIRA, 2007).

Environmental quality is based on the relation between human activities and the environment itself. The increasing speed of human actions and the environment's resilience – its capacity to return to balance – are the key elements of this concept. This relationship is modifying vital ecosystems and, recently, modifying Earth's climate. Even though we are surrounded by many uncertainties, there is a general agreement that mankind represents the most powerful force of transformation on the planet (DREW, 1998). Man's influence on environmental quality depends on two factors: the impact he has and the effort to undo or mitigate that impact (BAUMOL e OATES, 1975). Pearce (1988) emphasizes that these impacts are made indistinguishably by both poverty expansion and wealth accumulation. Hence, poverty and social inequality have direct influence on environmental quality. Examples of impacts include precarious sanitary systems, the accumulation of domestic solid waste in neighborhoods, land degradation, infectious illness, as well as resulting accidents that can be attributed to these conditions (PEARCE, 1988; MULLER, 1997; PEARCE, 1980). Generally, efforts towards mitigation of these social woes include actions with little or no environmental relationship. In fact, it can be the opposite.

In principle, mitigating efforts are exclusively related to the social development and do not consider environmental development (MARTINEZ-ALIER, 1997). According to Tinbergen's basic rule, a policy must have one single objective and its actions should not interlink socio-economic and environmental development goals in the same policy. The rule says that for every independent policy objective it is necessary to have an independent policy instrument or *"you cannot kill two birds with one stone"* (TIMBERGEN, 1952). If accepted, this means that reducing poverty and social inequality will not contribute directly to environmental quality recovery and protection, or *vice-versa*. However, policymakers misinterpret this basic rule because Tinbergen's independence concept does not imply unlinked actions. Thus, the problem with current development concepts is the limitation of its actions that do not consider synergies among different dimensions such as environmental development.

Development has been considered as an independent and unlimited process but the finite nature of natural resources and the environment's carrying capacity are obstacles to its sustainability. Thus, the concept of sustainable development (SD) is an attempt to tackle this problem.

SD has been broadened to become a new paradigm and form a hope for human impact mitigation. There is some consensus around its implementation; however, the imprecision of the SD concept causes worldwide debates regarding diversity of adoption and understanding. Debate varies from discussion about the neoclassic economy concept's incompatibility in incorporating the sustainability values, to the need of using differentiated economic theories (e.g., environmental and ecological economics) to analyze the SD implementation (DALY e TOWNSEND, 1994; DALY e FARLEY, 2010). Others question the iniquity of the current standard of development and its unfeasibility as model to be followed in search of sustainability (O'CONNOR, 1997; GUIMARÃES, 1997). They argue that there is a need for social strategies and policies that should be based on ethical posture of development (SACHS, 2004; ACSERALD, 2001). Clearly, the SD concept does not have an exclusive form of implementation because any development process is closely related to the cultural and geographical background where it is implemented (RUTKOWSKI, 2006; RUTKOWSKI, 1999).

3.1 The sustainability of development

The 1960s was characterized by physical distribution management development and the expansion of markets. All these developments were based on mass production techniques and productivity improvement strategies, which were previously developed in the 1950s. The economic growth in this period helped to consolidate the operational and logistics management in the 1970s. In the late 1960s and beginning of the 1970s, the Club of Rome discussed a methodology to extrapolate the future of global development.

The report from the Club of Rome delivered a polarized view. On the one side, it provided a technocentric perspective, in which environmental limits are overcome by technological innovation. In this view, economic growth and technology development have the ability to eliminate social disparities with an environmental cost, which was considered inevitable or irrelevant when compared to the potential benefits of such development. On the other side, it provided an ecocentric perspective based on the idea that the planet's natural resources and assimilative capacity of pollutants are not able to keep up with the current model of development expansion (MADDOX, 1972; RUTKOWSKI, 1999; RUTKOWSKI, 2006). The report was the origin of *The Limits to Growth*. However, the book publication presented a single perspective. The book argued that the problem was not the exhaustion of resources, but the growth model. The book received considerable attention and popularized the environmental issue. Its influence was such that it guided the discussions during the first United Nations Organization (UN) Conference on the Human Environment held in Stockholm in 1972 to discuss the increasing contamination of the environment (RUTKOWSKI, 2006).

In 1974, the Cocoyoc Declaration kept the discussion on development versus environment. The declaration added two new perspectives into the discussion. In short, it identified the relationship between demographic explosion and absolute lack of resources. The higher the poverty level, the higher is the population growth. It also argued that the environmental quality destruction was caused not only by poverty patterns but also by the high consumption patterns of developed countries (UNITED NATIONS (UNEP/UNCTAD), 1975).

In the following year, the UN Environmental Programme (UNEP), Dag Hammarskjöld Foundation, 13 other institutions linked to the UN and 48 countries combined forces to support the Cocoyoc Declaration's conclusions. The group published a report on the issue of power and its relationship with environmental degradation, especially the need for a new type of development based on the mobilization of social forces capable of changing the structures of the dominant development model (DAG HAMMARSKJÖLD FOUNDATION, 1975). The report confirmed that environmental quality degradation was caused by both expansion of poverty and accumulation of wealth. Therefore, environmental issues were directly related to overcoming not only the poverty through meeting basic human needs such as food, health, and housing but also the expansion of consumption patterns of the richest population (PEARCE, 1988; MULLER, 1997).

As a direct result of these discussions during late 1970s, the Brundtland Commission held a series of meetings among various sectors of society in order to discuss development alternatives between the years 1983 and 1986. These meetings concluded in the publication of the Brundtland Report in 1987. In this document, also known as *Our Common Future*, restated that instead of "growth" the problem was the development model. In addition, the report used the term *sustainable development* for the first time. Despite its popularity, there are still diverse approaches to the concept of sustainable development and the only consensus is the intergenerational commitment by assuming SD as the *"development that meets the needs of the present without compromising the ability of the future generations to meet their own needs"* (WORLD COMMISSION ON ENVIROMENT AND DEVELOPMENT (WCED), 1987; GUIMARÃES, 1997; RUTKOWSKI, 2006).

In brief, the Cocoyoc Declaration assumed that economic growth is not sufficient to ensure the sustainability of development because it can be extremely imposing and cause social exclusion. The declaration raised the debate that is necessary and possible to intervene in the development process and direct it in order to orchestrate economic, social and environmental developments. However, it was the Brundtland Report that named this form of intervention by introducing the concept of sustainable development. Yet, there is still no consensus regarding the implementation of this very intervention.

In 1992, the Earth Summit or UN Conference on Environment and Development (Rio92) in Rio de Janeiro is the landmark for the institutionalization of the concept of sustainable development. It fostered the discussion on environment preservation, which became gradually an important topic on the National agendas of various countries through their action plans. One example was the Agenda 21, which is a plan of action to be taken globally, nationally and locally by UN organizations, governments and civil society in all areas in which human activity impacts the environment. The agenda is an important benchmark since it constitutes the most comprehensive attempt ever undertaken to guide society into a new pattern of production and consumption. As a direct result, many laws and structures were designed for preservation not only of nature but also of human rights (PEARCE, 1988; RUTKOWSKI, 2006). Moreover, the Rio92 finally brought to light the relationship between economic development and environmental preservation raised by Cocoyoc and ratified by the Brundtland Report. Its success can be defined as the beginning of ecopolitics and the definition of institutional guidelines such as:

- Common but differentiated responsibility principle,
- Precautionary principle,
- Dissemination of the polluter pays principle,
- Right to information access, environmental justice and participatory decision-making,
- Importance of the regional dimension,
- Environmental impact assessment, and
- Corporate social responsibility, environmental and ethical principles embodied globally

Another success was the *"Think Globally, Act Locally"* motto, which could explain the growing trend of organizations assuming more responsibilities for environmental management (STEPHEN, 2004). As a result, companies started to take into consideration a way of becoming sustainable. One initiative was the foundation of the World Business Council for Sustainable Development (WBCSD) in 1992. Three years later, this initiative led to the World Trade Organization (WTO) formally recognized linkages between trade, environmental quality and development, which have fostered the creation of companies' environmental management structures and standards.

While Rio92 designed the future, the last major mobilization held in 2002 in Johannesburg, the World Summit on Sustainable Development (Rio+10) was an attempt to evaluate the progress and difficulties in the implementation of international agreements, to outline new policies recommendations, and to design a new strategic plan for development. Much has been said, but little has been done during the summit. During the course of Rio+10 was evident the weakening of Rio92's agenda due mostly to the reduction of the figure of the State and the deregulation of markets worldwide. Despite the early successes guided by the institutionalization of SD from 1992 to 2002, Rio+10 failed on pushing it further but it identified great challenges lying ahead such as:

- Clarifying the relationship between trade and multilateral agreements on environment protection,
- Ensuring the Stockholm Commitment on funding mechanisms and technology transfer,
- Articulating a regional vision of sustainability,
- Encouraging competitive advantages in terms of environmental services,
- Harmonizing policies instruments such as green tax and environmental management, and
- Creating systems for monitoring and evaluation of regional sustainability.

In order to tackle these challenges, it is necessary to not only operationalize the sustainability concept but also to be able of verifying this very sustainability in daily practices. So far there are no satisfactory answers to these problems. One reason is the lack of an exclusive way of measuring sustainability. Another reason is the difficulties on incorporating or identifying sustainability into daily practices (BOSSEL, 1998).

Nonetheless, it is evident that any solution, whatever it is, must have its starting point based on the idea that the current model of production and consumption does not admit any principle of self-limitation. Though, the solution is not a simple matter of zero growth. Society must begin to seek new outlets, new production models based on another type of growth, which is based more on quality of life than on economic efficiency (BOSSEL, 1998). Hence, the sustainability of development is finding means of production, distribution and consumption of existing resources in a more cohesive fashion, economically cost-effective, environmentally sustainable, socially just and territorially planned (FLUXUS, 2009).

3.2 Greening management practices

Greening management practices is one important component of SD. The development of industry goes together with irreversible environmental damages. On the other hand, industrialization led to remarkable development in the economic, social, political and technological dimensions. During the last three decades, policy instruments and business management structures and standards have been designed to control sources of environmental impacts using industrial zoning, environmental licensing, and emission standards. They were clearly developed to regulate large targets – such as manufacturing plants, iron-producing plants, refineries, chemical plants, and other "big dirties" – but the contemporary environmental problems are caused by smaller and more diffuse sources of pollution, which are more difficult to control using traditional regulatory approaches (SANCHES-PEREIRA, VILELA JR e RUTKOWSKI, 2009).

There is no doubt that standards, stringent monitoring and enforcement have achieved some success, especially in reducing air and water pollution. However, this approach is widely seen as inflexible and raises concerns over whether it inhibits innovation. For example: *How is it possible to improve environmental performance of companies that already have met the legal requirements? How is it possible to promote new environmental management systems? How is it possible to spread new cleaner technologies, programs, and production practices?*

Self-regulation can be seen as an alternative to this inhibition caused by "command and control" instruments, which can be defined as regulation by organizations or associations; not only creating the rules, but also monitoring compliance with these rules and enforcing them against their own members. An example of self-regulation is wide evidence that firms adopting an Environmental Management System (EMS) like ISO 14.001 improve their environmental performance. This is because ISO 14001's third-party audits reduce the chance firms will deliberately fail to comply with regulations and the EMS procedure reduces the chances firms will be in non-compliance due to ignorance. On the other hand, it is a challenge to make the connection between the private interests for the use of self-regulation and the public interests (SANCHES-PEREIRA, VILELA JR e RUTKOWSKI, 2009).

In this context, there are three categories or different approaches of self-regulation (BALWIN, CAVE e LODGE, 2011). *Pure self-regulation* is a strict private parties' initiative and government is not involved but it accepts the results as long as they are not against general rules such as those on fair competition (e.g., ISO 14.000 series). *Substitute type of self-regulation* is also a private actors' initiative but government oversees the process in order to safeguard the public interest that may be at stake (e.g., consumer rights). *Conditioned self-regulation* means that public and private interests are intertwined (e.g., "command and covenant" instruments).

3.2.1 Sustainability and industry

The first step towards sustainability is to act together on finding solutions. In order to do so, it is essential to recognize firstly the respective shares of responsibility and understand how others are affected by it (ALIROL, 2004). In this logic, industry representatives are admitting their share of responsibility and seeking solutions to change the impacts on the environmental and life qualities within their plants and outside their gates. The most commonly used tool for achieving that is the EMS.

The introduction of environmental management practices appeared as a new attitude within the industry to include exclusively environmental issues at first. Later, it evolved and included social and environmental issues through their environmental responsibility reports. Although their decisions on administrative practices and technology adaptions could be interpreted as increasing social and environmental concerns of the business rather than as financial investment, the real motivation was the desire to solve internal problems and "clean the house" (HAWKEN, LOVINS e HUNTER LOVINS, 2000; BARBIERI, 2007). Hence, their concerns were solely based on the perception of their own production processes, such as pollutant emissions, disposal of waste, minimization of health risks, compliance with the standards stipulated by the environmental policies, etc. However, issues related to SD, which were mainly focused on environmental issues, turned out to be an opportunity to rethink the values and productive practices of industrial competition (ALIROL, 2004; LIMA, 2008).

Lima (2008) argues that during the past 50 years, a number of approaches have been developed to meet the industry understanding on how the environmental issue should be treated at operational level. In this context, a variety of approaches were developed such as risk assessment analysis, material intensity analysis, life cycle assessment, environmental management system, environmental communication and reporting, environmental certifications, pollution prevention programs, etc. The difference between these approaches is related to their function-unit and geographical and temporal scale (LIMA, 2008).

At the operational level, each approach entails the adoption of an environmental management strategy related to the current perception of the industries on environmental issues. Since the perceptions have changed through time, so have the approaches. They change from dealing with pollution emission problems to balancing production system. The chronological division set by Lima (2008) illustrates the different business approaches in relation to its perception on environmental responsibility (LIMA, 2008). Table 1 illustrates the chronological division containing five historical moments that represent the guiding perspective of the industrial sector in that given period.

Table 1: Evolution of industrial sector's perspective in connection to environmental problems (LIMA, 2008)

Guiding Perspective	Historical moment and influences
"There is no problem"	This perception prevailed until the late 1960s. During this period occurred an extensive development of operation tools for mass production and productivity improvements.
"There is a problem but it is not my fault"	This mentality of not taking the blame prevailed especially in the early 1970s. It was a defensive speech against the increasing pressure from communities and environmental movements, which blamed industries for the contamination of the air and waterways. During the same period, companies started to optimize internal operations helped by the growing application of computer in business management.
"There is a problem and I know how to solve it alone"	During late 1970's and early 1980s, industry representatives admitted their share of responsibility regarding environmental problems. It was a reaction to the increasing pressure from environmental groups and local communities. However, the industrial approach was based on "end-of-pipe" solutions such as placing filters, dilution of pollutants before their release out of the factory, or moving them away from the factory and influential surrounding communities. At management level, this period was characterized by the development of process-oriented management and expansion of the organizational boundaries of companies.
"The problem can be solved in its origin"	The 1990s was characterized by the intensification of process-oriented management. Also, a new integrated management changed the production process of raw materials and other inputs. This has helped spreading out cleaner production strategies, industrial metabolism concept and industrial ecology theory.
"Standing alone cannot solve the problem. It needs a system's approach "	The 2000s was driven by the search of interconnection among productive activities. It was characterized by an increasing integration between production networks and information technology. The industrial perception of environmental problems evolved and included not only environmental issues but also social problems through their environmental responsibility reports. It was the beginning of an industrial network positioning.

At the strategic level, each management instrument has a different use. As a result, different instruments can focus on the product, or production process, or administrative activities within the system. Hence, Glavič & Lukman (2007) propose four levels of complexity (GLAVIČ e LUKMAN, 2007). Table 2 lists the most common management instruments used by the industrial sector and organize them in an increasing order of complexity: Principles, Approaches, Subsystems, and Sustainable Systems.

Table 2: The complexity level of strategic management instruments (GLAVIČ e LUKMAN, 2007)

Complexity Level	*Strategic Management Instrument*	*Reference Number*
Principles	Environmental Accounting	1
	Degradation	2
	Eco-efficiency	3
	Factor 10	4
	Ethical Investment	5
	Minimization of Resource Usage	6
	Mutualism	7
	Polluter Pays Principle	8
	Purification	9
	Recycling	10
	Recovery	11
	Renewable Resources	12
	Source Reduction	13
	Regeneration	14
	Reporting to Stakeholders	15
	Remanufacturing	16
	Repair	17
	Extend Producer Responsibility	18
	Social Responsibility	19
	Reuse	20
	Health & Safety	21
Approaches	Voluntary Environmental Agreement	22
	Life Cycle Analysis (LCA)	23
	Pollution Control	24
	Eco-design	25
	Supply Chain Management	**26**
	Environmental Legislation	27
	Waste Minimization	28
	Cleaner Production	29
	Green Chemistry	30
	Zero Waste	31
Subsystems	**Industrial Ecology**	**32**
	Environmental Engineering	33
	Pollution Prevention (P2)	34
	Integrated Pollution Prevention and Control	35
	Environmental Management Systems	36
	Product Service System	37
	Environmental Technology	38
Sustainable Systems	Sustainable Consumption	39
	Responsible Care	40
	Sustainable Production	41

Principles are fundamental concepts. They provide guidance and establish grounds for actions. Hence, principals are restricted to one single activity or method. For example, *Polluter Pays Principle* states that those causing the pollution are responsible for paying the costs related to it. Thus, principles can be considered as a narrow directive but they are important as basis for the establishment of more complex actions such as approaches.

Approaches cover a group of principles by connecting them with strategies and activities related to a broader topic. For example, *Cleaner Production* combines environmental and economic principles into its strategy to organize production activities.

The combination of approaches increases the complexity of the strategic management instrument. As a result, subsystems introduce actions with a holistic perspective in order to achieve integral environmental preservation and long-term societal welfare such as EMS or Product Service System (PSS).

Finally, sustainable systems is a group of interdepended and inter-related complex activities towards sustainability and they demand a change of society's lifestyle, production system and consumption patterns (GLAVIČ e LUKMAN, 2007).

In addition to classifying the strategic management instruments based on its complexity, Glavič & Lukman (2007) created a three-dimensional model to illustrate the positioning of these instruments and their inter-relationship with the economic, environmental and social dimensions towards sustainability.

Figure 1 presents the Glavič & Lukman's tetrahedron. It shows not only the complexity of the instrument but also its degree of affinity with the economic, environmental and social dimensions. In this sense, those located in central positions within levels are more balanced among the three dimensions. The higher the level, the closer the strategic management instrument is to the sustainability dimension. It is valuable to emphasize that all instruments are important. Those situated in lower levels are the building blocks of sustainable development (GLAVIČ e LUKMAN, 2007).

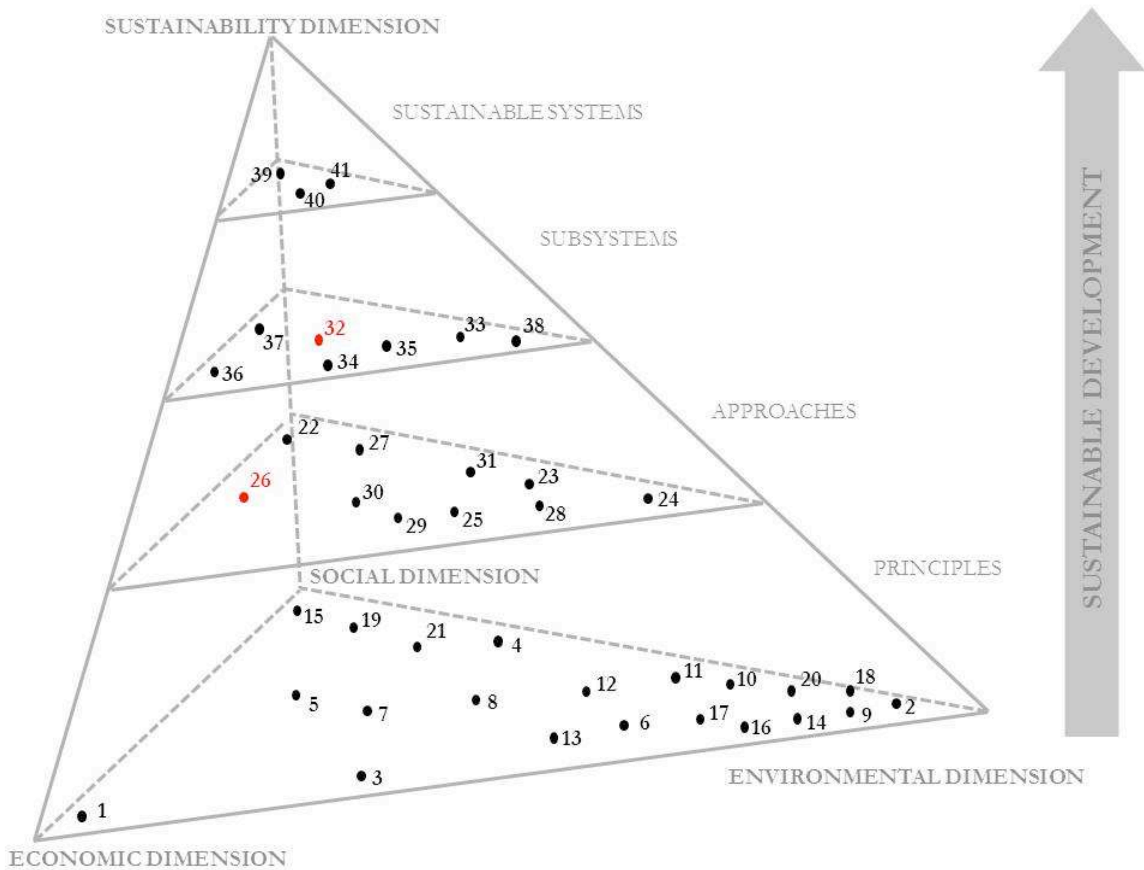

Figure 1: Adaptation of the Glavič & Lukman's Tetrahedron (GLAVIČ e LUKMAN, 2007)

The Supply Chain Management (SCM) and Industrial Ecology Theory (IE) are represented respectively in the tetrahedron with the numbers 26 and 32. The positioning of IE at the subsystems level is an indication that it can provide a new paradigm for business and steer supply chain management systems to facilitate and promote a more sustainable way of production.

Industrial Ecology and sustainable supply chains

Industrial activities until late 1970s were designed independently of their impacts on the environment. As a result, environmental issues were set-aside during the decision-making process of productive activities such as the ascending pollutant emissions from industrial systems. The first regulatory measures were focused on the consequences of contamination in the environment in spite of restraining pollutant emissions. Technical solutions arising during this period were based on "end-of-pipe" treatments, consisting of processes of remediation, treatment and disposal of specific pollutants existing in industrial waste (SANCHES-PEREIRA, LIMA e RUTKOWSKI, 2007).

With the intensification of environmental problems and increased social pressure during the 1980s, the proposed control mechanisms were not sufficient because they did not attack the causes of the problem. The search for better answers gave way to other approaches in this area. New concepts and methodologies were developed that later turned out to be incorporated by the Industrial Ecology movement such as Pollution Prevention (P2), Cleaner Production, Design for the Environment (DfE), and Life Cycle Analysis (LCA). Though early studies and experiences related to industrial metabolism and industrial ecology have begun in the 1970s and some can be drawn back to the 1950s, it is during the late 1980s and early 1990s that these concepts have gained considerable momentum. Since then, the Industrial Ecology (IE) has increased its strength as an integrating strategy for industrial processes development and environment protection. IE's goals are clear and are based on three pillars: sustainable use of resources, environmental preservation and promotion of intergenerational equity (SANCHES-PEREIRA, VILELA JR e RUTKOWSKI, 2009).

One of IE's keystones is the article *"Strategies for Manufacturing"* by Robert Frosch and Nicholas Gallopoulos published in Scientific American in 1989. It is one of the earliest references to the construction of the IE concept. The article presented the concept of an industrial ecosystem and transformed the traditional model of perceiving industrial activities in which each plant individually, requires raw materials and generate products to be sold and waste to be deposited. The new model presented a more integrated system in which the consumption of energy and materials is optimized and the effluents of one process serve as raw material to another (SANCHES-PEREIRA, LIMA e RUTKOWSKI, 2007)

Erkman *et al.* (2001) present seven key points that characterize IE (ERKMAN, FRANCIS e RAMASWAMY, 2001). They are:

- Systemic view of interactions between industrial systems and the environment;
- Study of flows and transformation processes of matter and energy;
- Multidisciplinary approach;
- Reorientation of manufacturing processes;
- Substitution of linear processes of production for cyclic processes;

- Industrial efficiency, and
- Promotion of synergies.

In the current hegemonic economic model, which does not admit any principles of self-limitation, IE seeks to intertwine flows, connect production activities into network, and mimic natural cycles. Thus, IE does not only promote interconnection but also identify changes necessary to implement the sustainability concept in production systems. Hence, it is important to understand cyclical patterns of resource usage and relationships among production systems, distribution flows and their impacts in the environment. The distribution of products appears to be an increasingly determining factor for the industrial sector (LIMA JR, RUTKWOSKI, *et al.*, 2010). Therefore, it seems natural to focus on Supply Chain Management (SCM) as strategic approach for the materialization of sustainability. SCM has been a key element of business competitive strategy to enhance productivity and profitability. Its development was not driven only by internal motivation but by various external factors such as environmental concerns, new market values (e.g., fair trade products, green products, etc.), information availability, and so forth (VONGEIBLER, KRISTOF e BIENGE, 2010; SCHOLZ-REITER, MAKUSCHEWITZ, *et al.*, 2011).

Lambert *et. al.* (1998, p.1) describe SCM as:

> *"…the integration of key business process from end-user through original suppliers, that provides products, services and information that add value for customers and other stakeholders"* (LAMBERT, COOPER e PAGH, 1998).

In 2001, Mentzer *et. al.* (2001, p.18) have outlined a complementary definition that defines SCM as:

> *"… the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of individual companies and the supply chain as a whole"* (MENTZER, DEWITT, *et al.*, 2001).

Nowadays, the Council of Supply Chain Management Professionals (CSCMP) describes supply chain management as:

> *"… the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination*

and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies" (COUNCIL OF SUPPLY CHAIN MANAGEMENT (CSCMP), 2011).

Svensson (2007) and Cater & Rogers (2008) argue that in order for SCM to become sustainable, it should integrate and equalize economic profit, environmental and social goals to long-term performance of individual companies as well as their supply chains (SVENSSON, 2007; CARTER e ROGERS, 2008).

The performance optimization of supply chains is an important process to promote sustainable development, since production activities and products distributions flows are closely linked to environmental changes. In this context, the sustainable supply chain management concept in general is understood as the management of services, products and raw materials along the chain – from suppliers to manufacturer and/service provider to final consumer and back again in the cycle – with improvements to the environmental and social goals. The interaction between suppliers and consumers is understood by this work as the flows of energy, materials, and greenhouse gases emissions from suppliers to consumers (GUNASEKARAN, PATEL e MCGAUGHEY, 2004; SRIVASTAVA, 2007; SVENSSON, 2007; CARTER e ROGERS, 2008).

3.2.2 Correlation between the evolution of sustainability concept and supply chain management

Development is shaped by a variety of forces (e.g., economic, social, environmental and political). Such forces usually cannot be changed without encountering opposition from well-established interests. Balance among these conflicting interests requires the articulation of broad social goals by political leaders, which means tying together development interests *"in ways that are both productive and ecologically sound is a formidable undertaking, given the inertia or our political and economic structures"* (WEINBERG, EYRING, *et al.*, 1994). Thus, the principal conceptual questions are when and how decision-makers should intervene.

Within current production and consumption patterns, supply chains are important causal links between human activities and environmental changes. IE's key points are important elements in creating values for business, customers and stakeholders throughout a supply chain. Combining these elements within SCM can be defined as a systemic and strategic coordination of operations and decision-making both within a given organization and also among partners and stakeholders within a chain, with view towards improving the long-term sustainability of the whole chain.

Subsequently, this approach goes hand in hand with the ultimate objective of the SCM which is to improve the long-term performance interaction among actors within the network and materialize their values within a variety of organizational structures (LAMBERT, COOPER e PAGH, 1998; MENTZER, DEWITT, *et al.*, 2001; COUNCIL OF SUPPLY CHAIN MANAGEMENT (CSCMP), 2004). These considerations confirm the high relevance of SCM as a instrument to intervene in the current development model and foster the implementation of sustainable development. Figure 2 illustrates a summary containing important benchmarks for the evolution of the sustainability concept and the development of supply chain management. In this context, the development of a performance assessment strategy able to measure the sustainability of supply chains is an important approach to be able to deal with problems from shifting from the current linear model of production to a more cyclical one. Understanding that one crucial step towards a more sustainable future demands reliable sources of renewable energy, bioenergy supply chains will play a decisive role during the next decades. In this respect, if biomass is to compete with fossil fuels, there is a need to create more reliable and constant supplies of bioenergy on a long-term basis and a more efficient distribution to points of consumption in more sustainable ways (GOLD e SEURING, 2011).

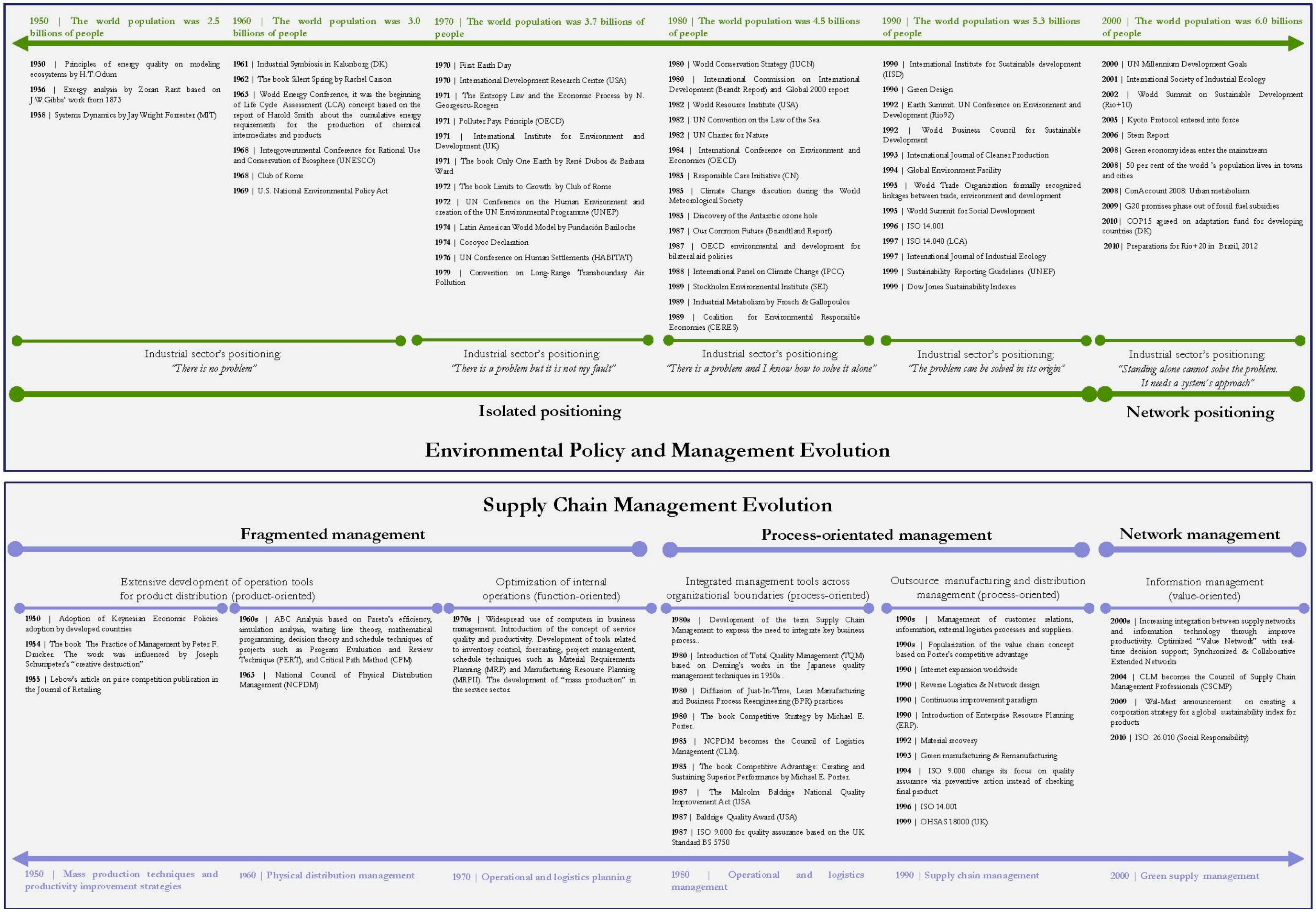

Figure 2: Correlation Timeline

The timeline organizes the correlation evolution between the environmental policy and management practices and supply chain management concept. We understand that different countries undergo different processes of development. Thus, the idea behind our correlation timeline is not to pinpointing a single country development (i.e., Brazil or Sweden) but to locate this very development on a broader perspective within a global scenario.

During the 1950s and 1960s, an extensive development of operational for product distribution took place. This period was characterized by physical distribution management development and the expansion of markets. All these developments were based on mass production techniques and productivity improvement strategies, which denied any environmental problem related to industrial production. Without a doubt, the economic growth in this period helped to consolidate the operational and logistics management in the 1970s. However, in the late 1960s and beginning of the 1970s, the society questioned the future of global development. In a global scenario, the management practices were fragmented and completely isolated from each other.

The industrial sector's positioning of not taking the blame prevailed especially in the early 1970s. It was a defensive speech against the increasing pressure from communities and environmental movements, which blamed industries for the contamination of the air and waterways. During the same period, companies started to optimize internal operations (e.g., function-oriented) helped by the growing application of computer in business management. Although management practices evolved from product-oriented to function-oriented, they were still fragmented and environmental issues were dealt by an isolated positioning.

The 1980s and 1990s were characterized by an intense global competition. The industrial sector admitted the share of responsibility regarding environmental problems. However, the industrial approach was based on *"end-of-pipe"* solutions such as placing filters, dilution of pollutants before their release out of the factory, or moving them away from the factory and influential surrounding communities. At management level, this period was characterized by the development of process-oriented management and expansion of the organizational boundaries of companies. This new integrated management changed production processes of raw materials and other inputs, which has also helped spreading out cleaner production strategies, industrial metabolism concept and the industrial ecology theory.

The 2000s mark the end of isolated positioning and the idea that it is necessary a systemic approach to balance conflicting interests of environmental protection and growing resources demand. An important aspect identified in the correlation timeline is the fact the supply chain management evolution used the praxis or the necessity of solving problems in daily practices while the environmental policy and management evolution was based on theoretical discussion to mitigate and/or avoid problems.

4 The bioenergy system and the dynamics of its supply chain

This chapter covers objectives 2 and 3. It presents basic concepts concerning bioenergy systems definition and its supply chain dynamics. Sweden provided a framework that is used as a baseline and/or analytical model for the supply chain management analysis. It discusses the role of biomass as a critical resource for renewable energy expansion. Hence, understanding the biomass system is critical to mobilize additional resources for bioenergy expansion but, also, it is important to avoid potential impacts of this very expansion in connection to resources competition and land use conflicts. Bioenergy system requires a well-organized and functioning supply chains with the purpose of overcoming these conflicts.

A larger use of bioenergy depends on resource availability and the establishment of effective production chains that can turn it into a competitive alternative among other renewables and conventional options. In 2010, a report on bioenergy from the European Climate Foundation (ECF) developed by a consortium of important Swedish companies including Sveaskog, Södra, and Vattenfall identified three main barriers to bioenergy expansion in Europe (EUROPEAN CLIMATE FOUNDATION, 2010).

The first barrier is the uncertainty regarding the long-term role of biomass as energy resource due to conservatism in the industrial sector that uses biomass resources (e.g., pulp & paper industries). Not only does the uncertainty hinder long-term investments in bioenergy infrastructures, but also the very development of bioenergy is seen as a risk among traditional biomass users. This leads to the second key barrier, which is the lack of infrastructures for transport and conversion of large volumes of biomass. The higher the uncertainty (e.g., first barrier), the lower are the investments made on infrastructure and conversion plants (e.g., second barrier). Finally, the third barrier is related to the bioenergy network in place, which has not yet been able to establish robust and clear sustainability criteria, and balance the interests of different stakeholders, whether at national or international levels. This, in turn, affects confidence on biomass resource availability and increases risks when it comes to quantity, quality and price of product, as well as demand volumes across the main supply sources.

Understanding the biomass system is critical to mobilize additional resources for bioenergy expansion. At the same time, it is also important to avoid or reduce negative impacts of a potential expansion, for example, due to land use conflicts and resource competition for multiple uses. In the case of Sweden, increased bioenergy use can result in more resource competition between forest products and forest-based energy carriers (EUROPEAN CLIMATE FOUNDATION, 2010; SANCHES-PEREIRA, 2011). Hence, the development of bioenergy requires well-organized and functioning supply chains with the purpose of overcoming these potential conflicts (MCCORMICK, 2007; SILVEIRA, 2005; FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO), 2004). In this study, we refer to the bioenergy system as both the technical aspects of bioenergy generation (i.e., as conversion technologies and biomass resources types) and overarching aspects of bioenergy development (i.e., policy frameworks, institutional capacities, infrastructure and actors' networks). One important aspect of the system is that while its expansion, distribution, and diversification has been largely based on locally available biomass resources, it often relies on investments in both small- and large- scale conversion technologies to meet the growing market demand for energy. In the meantime, markets for bioenergy carriers have gradually evolved from national to international contexts (SILVEIRA, 2005; MCCORMICK, 2007; SMEETS, 2008; MACQUEEN e KORHALILLER, 2011). Figure 3 illustrates the bioenergy system, it is important to address that there are no hierarchy or preferences among components within the bioenergy pathways. It just illustrates potential pathways.

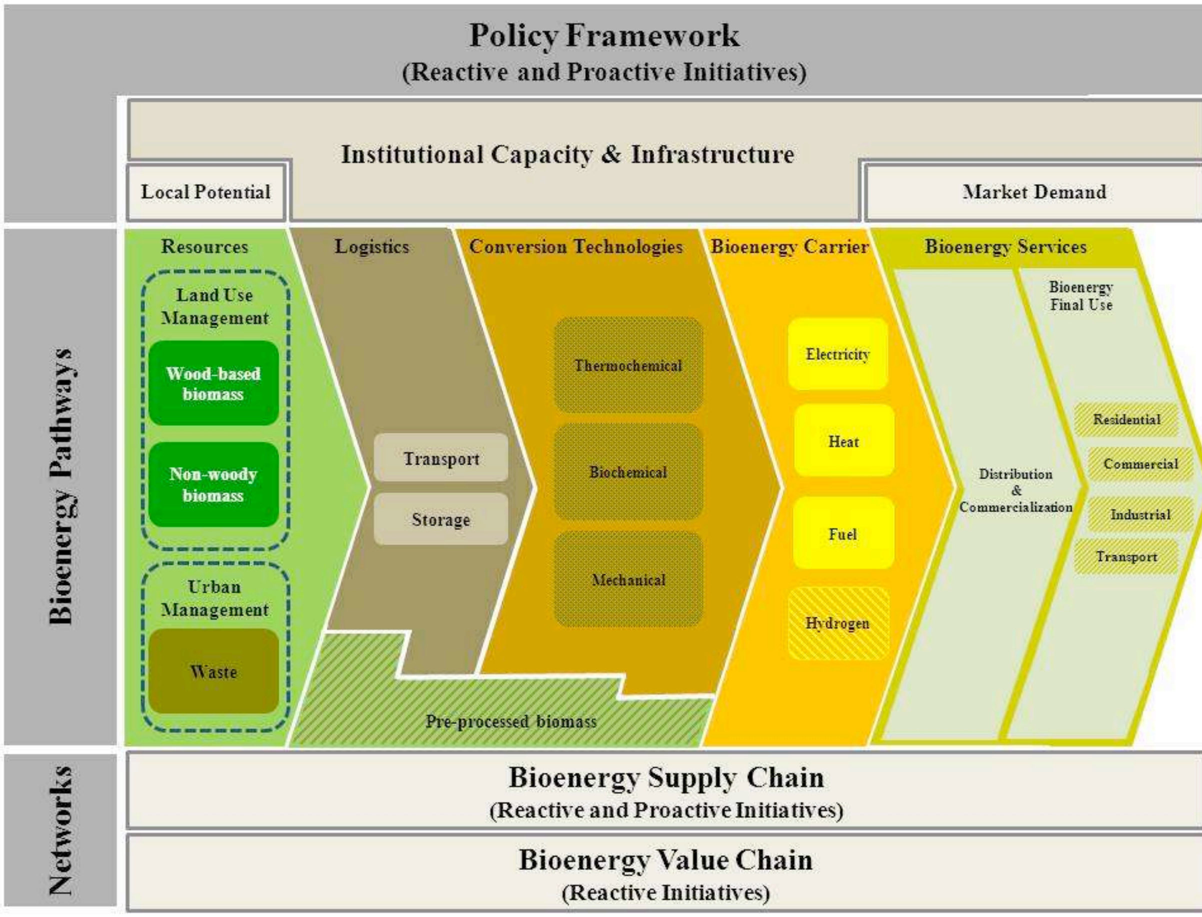

Figure 3: Bioenergy system diagram

The *policy framework* establishes clear goals or targets, creates rules and standards, design incentives, and defines effective communication channels in order to orchestrate a system development. In the case of bioenergy systems, the policy framework can either consider only one specific policy such as energy policy area or include a variety of inter-related policies such as environmental and agricultural policies. In the EU, security of energy supply, promotion of energy efficiency and energy saving initiatives, development of new and renewable forms of energy, interconnection of energy networks, sustainability and competitiveness to ensure the functioning of energy markets are central energy policy goals (EUROPEAN UNION, 2007). The materialization or implementation of the policy framework depends on institutional capacity to provide support for achieving the policy goals. For example, to promote the development of bioenergy requires setting goals not only to protect but also to enhance the use of local resources. Swedish energy policies foster bioenergy reflecting not only the country's resource availability but also its standpoint on environmental concerns, especially in connection to climate change mitigation actions (GOVERNMENT OF SWEDEN, 2009). In addition, the bioenergy policy framework requires institutional capacity to overlook national programs with sufficient technical expertise to ensure biomass production on a sustainable basis and bioenergy promotion, production standards, distribution, and use. Silveira (2005) and McCormick & Kåberger (2005) argue that bioenergy success largely depends on collaborative efforts of private and public institutions and flexible industrial structures capable of benefiting from synergies with other segments (i.e., forest-based industry) (SILVEIRA, 2005; MCCORMICK e KÅBERGER, 2005).

The Unified Bioenergy Terminology (UBET) from Food and Agriculture Organization of the United Nations (FAO) is an effort towards a common ground to facilitate understanding and discussion on bioenergy (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO), 2004). This study complements the proposed terminology by adding the resource management dimension. The resources are aggregated in connection to their management practice. Wood-based and non-woody biomass resources – which are related to sources such as forests, energy crops, agricultural by-products, agro-industrial by-products, etc. – are considered under the land use management category. The urban management category includes biomass resources related to urban activities such as recovered wood, municipal solid waste, sewage, end-use products, and industrial by-products.

Bioenergy pathways depend on a large variety of raw materials and conversion technologies for biomass use. Often, raw materials have to be pre-processed and converted to solid, liquid or gaseous fuels through mechanical, thermochemical or biochemical technologies before they can be used to provide energy services. The different conversion pathways allow many alternative structures for bioenergy networks that encompass a range of inputs and outputs, thus stimulating partnerships and creating synergies among segments. For example, pellets production has a strong symbiotic relation with specific segments of the forest-based industry (e.g., forestry activities, log manufactures, and sawmills). In this case, pellet producers rely on by-product flows generated by the demand for forest-based products (i.e., timber and wood boards). This symbiotic relation is both strengthen when it comes to efficiency in resource management but also a constraint as oscillations in the demand for forest products has a direct effect on the availability of residues for pellets production and, consequently, their price. Another example is the Brazilian biodiesel production. In this case, biodiesel producers need to consider how to incorporate their by-product (i.e., each 100 liters of produced biodiesel have around 10 to 15 liters of glycerol as by-product) into a symbiotic relation with other segments. Otherwise, biodiesel production can become environmentally burdensome.

Especially when biodiesel is produced by isolate communities such as those located in the Amazon region.

Conversion technologies play an important role on the definition of related infrastructure, which is necessary to define a bioenergy pathway. Nowadays, conversion technologies are not any longer a barrier to the bioenergy expansion as many alternatives are mature and commercially available (MCCORMICK, 2007). Nevertheless, research and development activities are expected to bring new technologies to the market in the near future, such as hydrogen and third-generation biofuels yet defining new pathways.

Networks manage the flows (e.g., information, material, and financial flows) within the system and they can add or create value. In the first case, networks add value on an existing product or service in order to meet value expectation of end consumers. In the latter, networks affect and form the end consumer's value thinking such as when a new product or service is introduced.

The concept of production chain management (e.g., supply and value chains) was popularized in the 1980s as an attempt to embody all value-adding activities ranging from individual perspective (i.e., single organization) to more complex networks. In short, the *supply chain perspective* emphasizes that all activities involved in providing products and services have to be accounted and managed. The *value chain perspective*, on the other hand, stresses that activities in connection to producing, processing, or providing products and services have a market value (PORTER, 1998a). Non-value adding activities are less interesting from the point of view of the value chain (PORTER, 1998c). However, that could be changed if new value is created for those same activities (e.g., a residue which previously was considered waste becoming a raw material for another production process). It is important to remember that markets often have problems internalizing environmental impacts. Therefore, non-value adding activities, as per defined by markets, should be revisited with the aim to create or capture the environmental and/or social values along the chains (PORTER, 1998b).

In general, value chains follow two different pathways. In the first pathway, the chain's scope emphasizes existing values. The network is used to meet the end-consumer's needs by adding value on existing product or service to fulfill existing market expectations. One example is that there is increasing demand for renewable energy in the market because there are end-consumers who value renewable energy higher than conventional sources. Hence, the network is used to meet this demand with value-added products or services (e.g., green certificates). Those actors within the network who react first to meet this demand have a competitive advantage. In the second pathway, the scope focuses on new values. In this case, the network is used to create a new product or service, which will generate new value. Smart grids are an example. They integrate actions from power generators and final users in such a way that the system can deliver reliable, affordable and sustainable electricity with added functions. The concept combines a number of practices and tools and implies the use of advanced technologies, but entails also a new final user behavior to achieve a more efficient electricity system (EUROPEAN COMMISSION, 2006). The smart grids create new value for energy end-consumers, for example by giving them the chance to become active players instead of passive consumers. The new service, which is based on an interconnected energy management system, enables end-consumers to better manage energy use and reduce their energy costs. Provided that effective business models are developed, smart grids have a competitive advantage in relation to networks not providing the same service.

In this study, we consider value chains as reactive initiatives based on end-consumer's value perception or on new values created through policy framework's interference. The pathway may be either one of the two. In the first case, the network reacts to meet end-consumer's existing values and, in the second case, end-consumers react to the new value offered by the network. In both cases, the materialization of these values happens through the supply chain, in which the management initiatives can be reactive or proactive. The reactive management defines the network's capability of rapidly responding to impacts on the supply chain. The proactive management is an effort to reduce uncertainties about the supply chain's potential impacts, not least identifying the limitations of various entities in the network.

For the purpose of this study, we will focus on the supply chain management (SCM) because it is through it that values are materialized in the bioenergy systems. In this context, SCM is understood as activities developed around the movement of raw materials, processing of these materials into finished products or services, and their distribution to final consumers. In order to perform these activities, supply chain professionals design and manage the material, information, and financial flows along the chain. The main objective of SCM is to improve the long-term performance interaction among actors within the network and materialize their values within a variety of organizational structures (LAMBERT, COOPER e PAGH, 1998; MENTZER, DEWITT, *et al.*, 2001; COUNCIL OF SUPPLY CHAIN MANAGEMENT (CSCMP), 2004).

4.1 Swedish bioenergy frame

There are several biomass options for replacing fossil fuel with biomass. Here, we focus on forest-based bioenergy which already represents 52% of total primary energy production from renewable energy sources in Europe. Needless to say, forests have always played an important role in the development of society (EUROPEAN COMMISSION, 2009). Forests have provided mankind with shelter, food and energy throughout history. Europe would not have developed without abundant wood supplies. In fact, Schubert (1957) pointed out that the Industrial Revolution was initially made possible due to a large availability of biomass resources. The wood and charcoal produced from forests were the energy carriers for the industrial development and continued powering growth until the end of 19th century when coal replaced wood as the dominant fuel. Coal, hydropower, oil, and natural gas rapidly replaced wood and animals as the dominant energy carrier and converters. The transition from wood to fossil fuels is as relevant as the transition from hunting and gathering to agriculture and finally industrial development (SCHUBERT, 1957).

Lately, the rising role of wood biomass as an energy carrier is often linked to emission reduction targets in the EU and to international trade. However, countries such as Sweden and Finland had taken advantage of their wood resources and potential long before climate change became a central policy issue in the EU. Therefore, they are often regarded as ones of the frontrunners concerning the development, promotion and implementation of renewable energy in the world. For example, the Swedish share of renewables in 2009 was 44.7% (SWEDISH ENERGY AGENCY, 2009). A very important part of this success lies on the national expansion of the bioenergy sector during the last few decades. Biomass contribution in the country has grown significantly and become one of the largest sources of energy in the current final energy use. In the last couple of years, the bioenergy share has increased from 16% in 2007 to 22% in 2009 and it is still growing. In the same period, oil and nuclear power – which are the other two largest energy sources – have decreased their share 1% and 5% respectively (SWEDISH ENERGY AGENCY, 2010b). As a result, biomass is not just an alternative but has conquered its place as a major reliable energy source.

4.1.1 Dynamics of forest-based bioenergy supply chain management

The interactions that happen within a network are understood as supply chain dynamics which implies a variety of actors operating at different structure levels, combining efforts in order to deliver products to customers. This means that management and control of flows must involve inter-relations among actors. As any complex system structure, supply chains need strategies and information exchange at different structure levels. At an overarching level, this includes general information such as inventories, statistics, policy targets, etc. This information could be in the public domain while specific information (e.g., detailed information about a region) may require further investigation. At company level, there are strategies related to business model, market competition, planned production, price mechanisms, etc. These strategies are not in the public domain but reflect the response of various actors to opportunities in the market and to changes in the business environment (SEURING, 2009; HAARTVEIT, KOZAK e MANESS, 2004). As a result, an effective strategy for SCM depends on the specific characteristics and complexity of the chain under examination.

The supply chain complexity is defined by a variety of flows contained within its scope. Figure 4 presents a range of flows based on the work of Haartveit *et al.* (2004). The flows have specific characteristics which directly define the supply chain structure and, therefore, its configuration and complexity (HAARTVEIT, KOZAK e MANESS, 2004).

In Figure 4, geometric shapes represent the structure components. Squares exemplify final product, circles represent raw material source or partially manufactured product, and arrows symbolize the flow. The scope is understood as the selection of structure components, where each one of them presents a detailed flow and so has a direct impact on the final organization or structure of the chain. The complexity is highlighted by the scope that is pictured in the color blue and, by default, the supply chain under investigation.

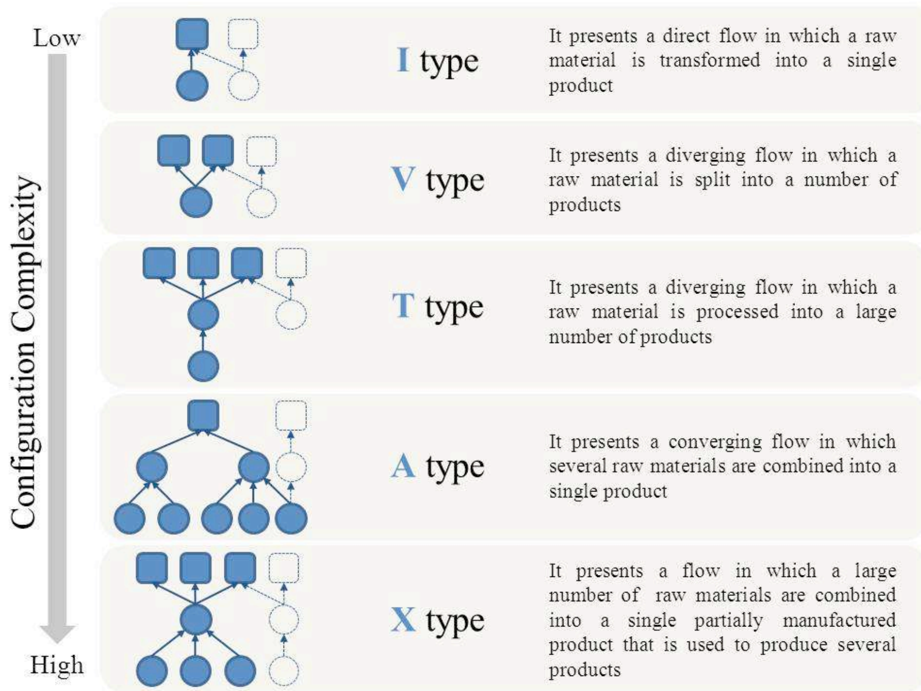

Figure 4: Complexity of supply chains flows adapted from Haartveit et.al. (2004).

In reality, no model can fully capture the complexity of a supply chain, including all flows and process aspects. Therefore, Min & Zhou (2002) suggest that, in order to reduce the uncertainties between reality and model, boundaries of the supply chain in question need to be clearly defined. By doing so, it is important to have a clear vision of the supply chain's structure components. They have to replicate the network along the chain in such a way that it is as close to reality as possible, reflecting key characteristics and dimensions of the supply chain in an "easy-to-understand" fashion (MIN e ZHOU, 2002).

Since Bioenergy SCM is initially based on the understanding of the movement of raw materials towards different carriers and eventually energy services, a natural starting point to define the scope of this study is to focus on the energy carriers (e.g., electricity, heat, or biofuels) and to map their raw material flows starting in the forest-based industry. The higher the flow's complexity, the greater the number of structure components is required to exemplify it and *vice-versa*. The next step is to define the supply chain levels, which includes location-allocation decisions that define the flows. These levels may be defined by local or regional or global demands.

The forest-based industry, for example, presents an integrated system which synchronizes a series of structure components at different levels in order to: (i) acquire raw materials and partially manufactured products, (ii) transform them into finished products, (iii) add value to these products, (iv) distribute and promote them to either retailers or customers, and, finally, (v) facilitate information exchange among various actors within the network (MIN e ZHOU, 2002).

We simplified the boundaries of this industry as presented in Figure 5. Circles characterize raw material (e.g., wood), squares exemplify partially manufactured or final products (e.g., wood board or timber), triangles symbolize raw material source or partially manufactured product from outside the forest-based systems (e.g., chemical products), and arrows represent the flow. Arrows pictured by solid lines represent distribution flows and dashed-and-point lines describe by-product distribution flows – such as sawdust or wood chips or black liquor flows. Finally, the geographical levels are highlighted by the color red.

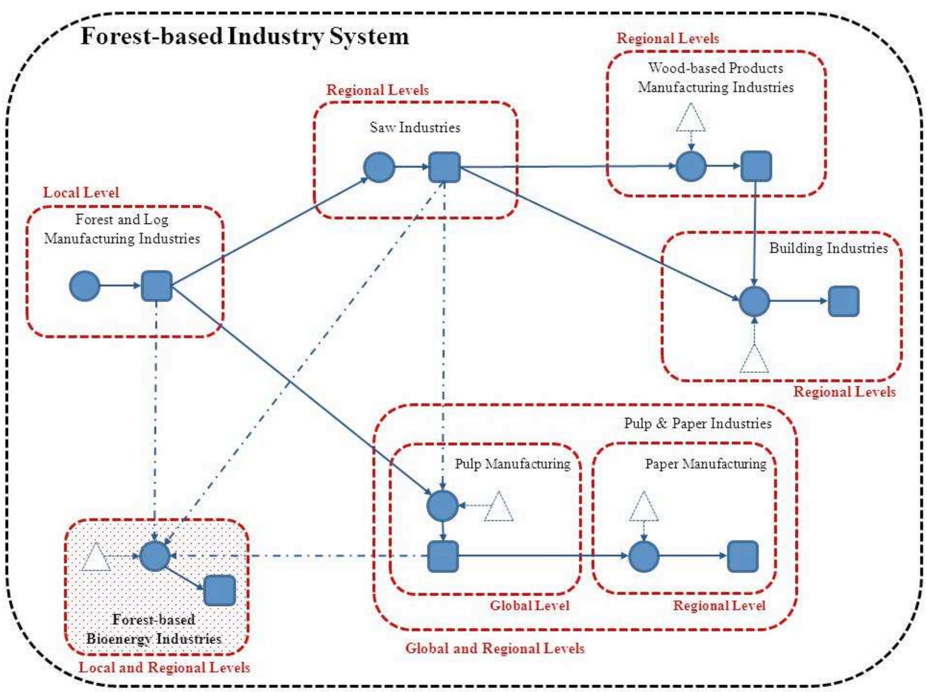

Figure 5: Forest-based Industry simplified supply chain scope.

A symbiotic relation exists between the supply of forest-based biomass for different segments of the forest-based industry and forest-based bioenergy generation. A significant characteristic of the Swedish bioenergy segment is that its development has occurred based on a symbiotic relation with forest industry. In fact, forest-based bioenergy generation in Sweden is almost entirely dependent on by-product flows generated by the demand for forest-based products (i.e., timber, wood boards, pulp wood, pulp, paper, etc.). Most of the biomass used for heat and electricity generation in the country comes from forests as wood fuels, black liquors, and tall oil. In 2010, for example, biomass supplied 46.8 TWh to district heating, where 32.4 TWh come from forest biomass. Wood fuels represent 31.6 TWh and 0.8 TWh were supplied from black liquor and tall oil. The wood fuel main sources are logging residues, which include low quality round wood, and by-products from the forest industry such as sawdust and wood chips (SWEDISH ENERGY AGENCY, 2011).

We understand that the definition of the system's boundary should be based not only on available information on the supply chain into consideration but also on the network relations that characterize inter-related business processes, emphasizing bioenergy systems in this case. Two different approaches have been proposed. In the first, Stevens (1989) presents a guideline based on the three levels of decision hierarchy: competitive strategy, tactical plans, and operational routines (STEVENS, 1989). Conversely, Cooper *et al.* (1997) suggested a different approach based on three structures: the type of partnership within a supply chain, the structural dimensions of a supply chain network, and the characteristics of flows among supply chain partners (COOPER, LAMBERT e PAGH, 1997). Both approaches offer the basis for defining the boundary of a supply chain and an analytical model.

In spite of great development in modeling supply chains, there are still many areas for improvements. One of these areas is the dynamics of local supply chains. For example, forest-based chains could be perceived as bottlenecks in the development and expansion of bioenergy systems. The majority of the current models applied to analyze the dynamics within local networks do not consider the inter-related business processes (SEURING, 2009). On the other hand, local networks often lack a specific goal, which means, *"they have difficulty in developing appropriate performance measures that can be targeted or benchmarked by a supply chain partner (p.235)"* (MIN e ZHOU, 2002). This occurs because the knowledge related to essential components of the supply chain is missing. Hence, an effective strategy for applying SCM requires reinforcing the local network goals or vision. In addition, the use of SCM is greatly restricted to cost effectiveness but, nowadays, is commonly related to excellence of service, specifically in large-scale chains. When it comes to local-scale chains, they generally benefit from nonexistent competition and, for that reason, lack customer service excellence in pursuing profit and competitive advantage.

Independently of scale, it is clear that different kinds of chains have different kinds of priorities guided by stakeholder pressure. Freeman's stakeholder model describes three levels of analysis: relational level, process level, and transactional level (FREEMAN, 2010). Figure 6 shows a generic stakeholder map adapted from Freeman (2010, p.55).

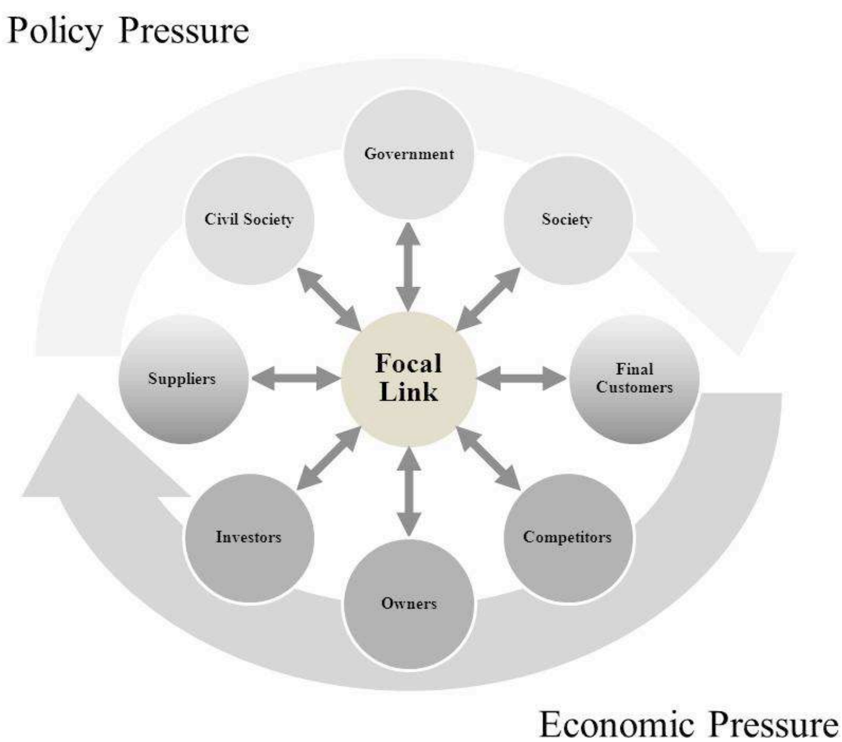

Figure 6: General stakeholder map adapted from Freeman (2010).

At the relational level, Freeman seeks an understanding of "who the stakeholders are". In order to do so, he uses a general stakeholder map as a starting point. The map presents the relationship connections among stakeholders and a focal link, which can be defined as a company, a group, a segment or a sector (FREEMAN, 2010; ELIAS e CAVANA, 2000). For example, Olson *et al.* argue that the use of wood pellets for energy in Europe first took-off in forest-rich countries – such as Sweden, Finland, and Austria – due to a policy pressure mostly related to environmental concerns and a strong economic benefit. In recent years, driving forces such as government support for renewable energy have increased the demand for pellets in Europe, which are now used as energy source in different scales. In Sweden, they can vary from residential to large-scale consumption in district heating and combined heat and power, thus bringing together different types of stakeholders along the chain (OLSSON, HILLRING e VINTERBÄCK, 2011).

The analysis focuses on focal link as forest-based bioenergy industries. In order to illustrate how it is connected in the forest-based industry system, we provide a simplified scope picturing the inter-related business processes and network relations in Figure 7.

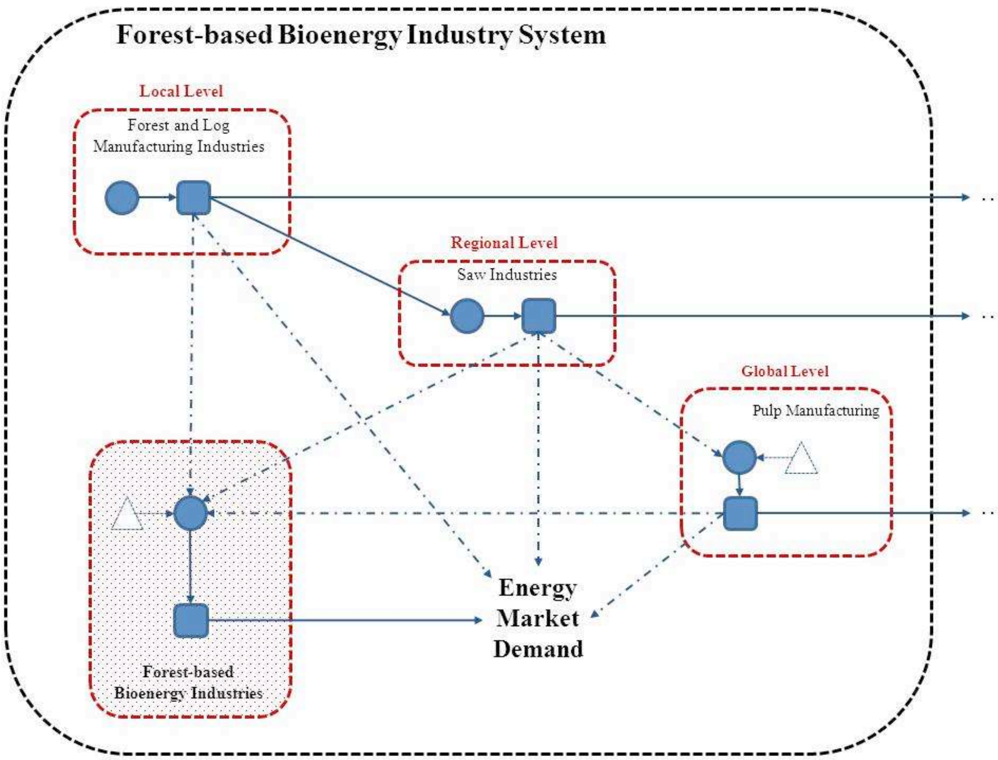

Figure 7: Forest-based bioenergy industry system simplified supply chain scope.

The reduced scope illustrate the symbiotic relation between the Swedish forest-based bioenergy industries and wood supply flows within specific segments of the forest-based industry such as forestry, log manufactures, sawmills, and pulp manufacturing plants. It shows that forest-based bioenergy relies on by-product flows generated directly by the demand for forest-based products (i.e., timber, wood boards, or pulp). An interesting aspect is that, from a production system's perspective, this symbiotic relationship is an advantage for resource efficiency. However, from a bioenergy system's perspective, the symbiotic relation is essential and, consequently, more important than the core production chain. Meaning, energy carriers have more value-added than other products.

In the current scenario, in which an increasing number of countries are favoring bioenergy, the bioenergy demand is likely to increase as well as the demand for forest-based energy carriers. This could lead to relatively inexpensive local supplies of forest-biomass reaching their limits and opening a higher demand not only for imported resources but also for more expensive local resources. In this respect, this new competition may well rearrange the forest-based industry network by restructuring its supply chain structure, rearranging flows, and redefining market boundaries. For example, the supply chains of bioenergy carriers could change from being based on by-product flows, which are entirely generated by the demand for forest-based products, to being based in a new distribution flow competing in the market with other forest-based products. As a result, bioenergy expansion could lead not only to land use conflicts but also to resource competition. In the case of Sweden, one potential conflict could be the competition between forest-based products (i.e., pulp and paper) *versus* forest-based bioenergy (SANCHES-PEREIRA, 2011).

According to Freeman (2010) and Elias & Cavana (2000), it is necessary to understand how a system either implicitly or explicitly manages its relations within the network and how the stakeholders legitimate their transactions or negotiations. Transferring this to the context of bioenergy expansion, this analysis perceives the need for understanding how the structures allocate resources, adjust processes, and communicate their performance (FREEMAN, 2010; ELIAS e CAVANA, 2000).

5 A management strategy for sustainability performance assessment

This chapter covers objectives 3 and 4. It presents the Performance Assessment Strategy (PAS). The proposed strategy can be applied at a variety of levels from a single company standpoint to more complex networks such as an organization group, an industrial segment or a productive sector. The strategy can be an effective instrument for understanding not only network flows but also supply chain management weaknesses and strengths related to sustainability aspects. This final chapter also retakes the research question and draw conclusions based on the observations and on the comparative analysis previously presented.

The evaluation of supply chains has conventionally been based on price variation rather than product rejection and on-time delivery numbers. While product rejection is related to the quality of production processes, on-time delivery is connected to the reliability of commercial processes. As a result, supplier selection and product choice were mainly based on price competition rather than on quality and reliability. In the last decades, this approach has undergone radical changes and new elements to evaluate a supply chain have come into place (GUNASEKARAN, PATEL e MCGAUGHEY, 2004).

Bhagwat and Sharma (2007) argue that there are many other approaches used to measure SCM performance such as strategic measurement analysis and reporting technique system (CROSS e LYNCH, 1989), performance measurement questionnaire (DIXON *et al.,* 1990), strategic performance measurement system (VITALE *et al.,* 1994), integrated dynamic performance measurement system (GHALAYININ *et al.,* 1997), and holistic process performance measurement system (BHAGWAT e SHARMA, 2007). The Balanced Scorecard (BSC), on the other hand, has often been recommended and adopted as management linking business strategies with short-term actions (KAPLAN e NORTON, 1996). Its concept was designed in the early 1990s. Kaplan and Norton state that it was created in response to the limitations of the traditional financial measures of business performance ((KAPLAN e NORTON, 2000). Figges et al. (2002) argue that BSC is based on the assumption that the *"efficient use of investment capital is no longer the sole determinant for competitive advantages, but increasingly soft factors such as intellectual capital, knowledge creation or excellent customer orientation become more important"* (FIGGE *et al.,* 2002, p.270). As a result, several organizations adopted BSC as the footing for their strategic management system. However, its application is used to assess past financial performances to improve future ones. Managers use it to align business practices to new strategies, *"moving away cost reduction and towards growth opportunities based on more customized, value-adding products and services"* (BHAGWAT e SHARMA, 2007, p.45). Table 3 summarizes the nine elements of BSC.

Table 3: BSC elements and alternative terminology (WAGNER e KAUFMANN, 2004)

BSC element	Alternative terminologies	Descriptions
(1) Strategic objectives	Strategic goals or bubbles	Long-term goals to be achieved in order to enhance company performance.
(2) Perspectives	Dimensions, aspects, or levels	Multi-dimensional aspects of business to meet the requirements of the major stakeholders.
(3) Cause-and-effect relationships	Interrelationships	Causal link between strategic objectives within one perspective and between strategic objectives across perspectives.
(4) Indicators	Key performance indicators (K PIs) or performance measures	Financial and non-financial indicators/ratios that track the implementation progress of the strategic objectives.
(5) Targets	Values	Target values for indicators
(6) Strategic initiatives	Actions, measures, or to-do's list	Tasks to be accomplished in order to achieve strategic objectives
(7) BSC-matrix	BSC-card	Strategic goals, indicators, and targets for each perspective displayed in matrix format.
(8) BSC-map	Strategy map or cause-and-effect diagram	Graphical or visual representation of cause-and-effect relationships and hypotheses about the relationship strengths.
(9) BSC-story	Three liner or story of the strategy	Verbal description of strategic objectives and cause-and-effect relationships and the hypotheses.

The BSC's four dimensions are financial perspective, customer perspective, internal process perspective, and learning and growth perspective. The financial perspective assesses whether the change of business strategy leads to improved economic success. The customer perspective defines the market segments in which the business competes. The internal process perspective identifies internal business processes that enable the organization to meet its goals. Finally, the learning and growth perspective describe the infrastructure for reaching the objectives (FIGGE *et al.,* 2002). These four dimensions do not promote interconnection nor identify changes necessary to implement the sustainability concept in production systems because they do not understand or incorporate cyclical patterns of resource usage and relationships among productions systems, distribution flows and their impact in the environment. Therefore, it seems natural to focus on broader perspective to combine the evaluation elements and attend the IE's seven key points.

Despite BSC approaches offer means of performance assessment not solely driven by financial results, the tool is still not able to foster supply chains to become more sustainable (FIGGE *et al.,* 2002). BSC may help to operationalize the sustainability concept within the network performance but it is not able of verifying this very performance in daily practices. Wagner and Kaufmann (2004) pointed out that BSC needs a strong top-down commitment, support from consultants, sustainability vision and strategy already in place in order to identify strategic objectives and cause-and-effect relationships (WAGNER e KAUFMANN, 2004).

On the other hand, due to the BSC's close link between SCM and operations management and strategy, it provides a valid starting point to define the evaluation elements used to promote and strengthen the chain inter-relations based on:

- *Suppliers evaluation*, which is related to efficiency, material flow, process integration, responsiveness and customer satisfaction;
- *Strategic evaluation*, which focuses on quality level, cost saving initiatives, legal compliance and market forecast;
- *Tactical evaluation*, which includes capacity flexibility and financial flow; and
- *Operational evaluation*, which measures company's ability in daily routines to avoid losses and its compliance to planned production schedule.

Evaluation indicators can stand-alone as well as be combined in order to provide better understanding of initiatives within the supply chain. Their arrangement reflects the ways in which SCM initiatives affect the network flows and, consequently, their performance.

The evaluation elements were combined and translated into Newman's (2009) four competence dimensions which are relevant to the focal link's capability of keeping a competitive standpoint in the market and incorporating a cyclical perspective to production systems. The four dimensions are coordination, understanding, improvement, and design. Coordination describes the focal link's ability to respond or adjust to short-term requirements (e.g., meeting an increased demand for heat). Understanding relates to its awareness of partners' capacities, chain limitations and market's requirements (e.g., increasing raw material demand and meeting product's certification standards). Improvement describes processes enhancement and the value-adding flow within the network (e.g., transformation of forest-based biomass into high-quality energy carriers). Finally, design defines the market specifications and long-term goals (e.g., energy carriers designed for future commercial and/or household markets). Thus, these competence dimensions vary from a more strategic perspective to potential improvements in the routines and flows within the chain (NEWMAN *et al.*, 2009). Unlike existing frameworks that are based upon the flow of material and information through the supply chain, Newman's four-competence dimensions framework captures the combined and overlapping impact of supply chain initiatives from a more strategic perspective and, for that reason, closer to the seven key points of IE.

From a practical point of view, the study classifies the ways in which SCM initiatives affect the network as reactive and proactive. Reactive initiatives refer to the company's capability to respond rapidly to impacts on the supply chain. Proactive initiatives are efforts made to reduce uncertainties related to potential impacts on the supply chain and to identify limitations of various entities in the network. Some initiatives can be reactive and proactive at the same time. As a result, they can overlap during decision-making processes. For example, short-term requirements, even though being just reactive actions, can create potential impacts in the network's operation in the long run.

In an effort to develop a strategy for performance assessment, we combined evaluation elements that translate competence dimensions into indexes. We also classified the resulting indexes as reactive and/or proactive according to the type of initiatives, as per discussed above. Figure 8 portrays this integration as a performance assessment matrix.

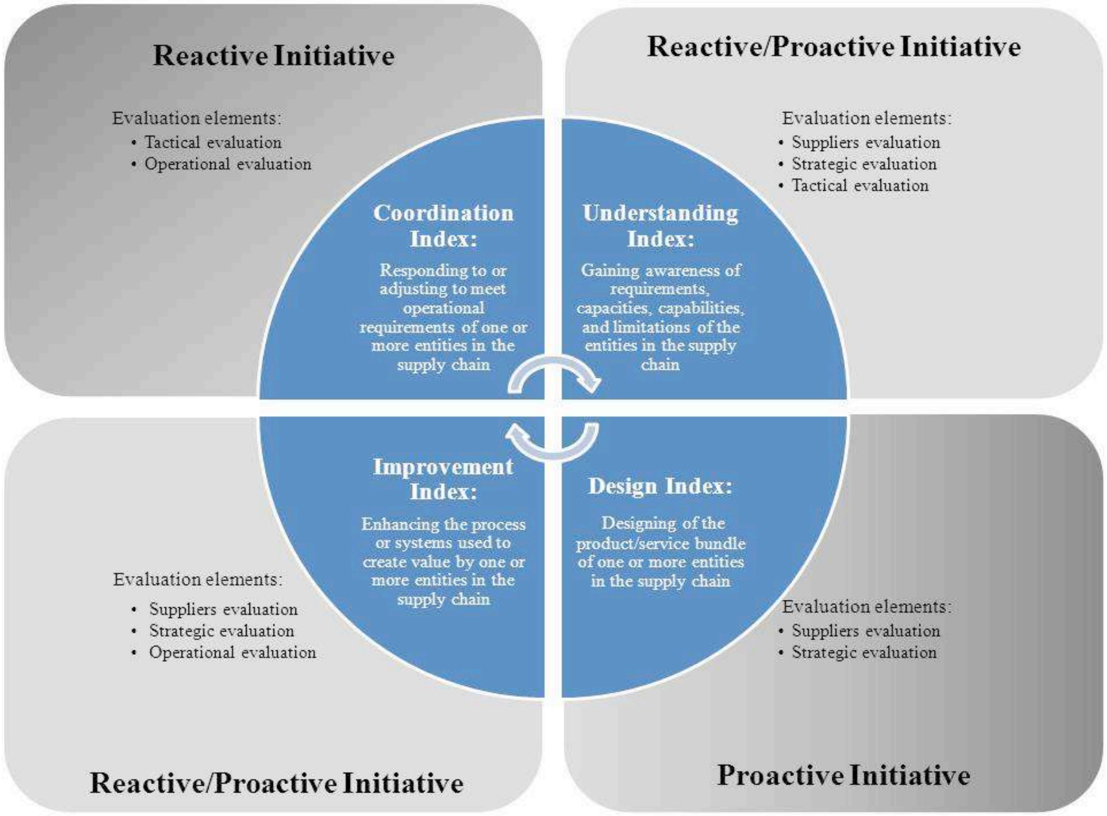

Figure 8: Performance assessment matrix.

At the core, Figure 8 presents the focal link's competence indexes classified as reactive, proactive, or both. The functional overview is rooted in the evaluation elements related to each specific initiative. The matrix guides the performance assessment of each competence index and their inter-relations. Based on the evaluation elements, the matrix can portray the performance assessment of each initiative.

In short, the matrix's objective is to synchronize the efforts of all stakeholders within the network — suppliers, manufacturers, distributors, and customers — in order to forge much closer relationships among all links in the value chain. The strategy is to increase the level of trust among vital links in the supply chain. By doing so, it increases the exchange of information and creates more accurate, "up-to-date" knowledge of demand forecasts, inventory levels, capacity utilization of resources, production schedules, delivery dates and other data that could help supply chain partners improve performance.

The matrix incorporates a cyclical perspective to production systems, which expands efforts to manage the supply chain as one overall process rather than independent functions or processes. It leverages the core competencies of each stakeholder, reorganizes information exchange, changes management processes and incentives a systemic perspective.

Finally, the matrix helps to identify and implement the sustainability perspective to transform the supply chain completely and deliver customer value through a process of distribution and consumption of existing resources in a more cohesive fashion, economically cost-effective, environmentally sustainable, socially just and territorially planned.

To make this matrix useful it is necessary to identify all structure components and their flows (see Figure 4) within the chain under examination. This is an important step because the overall performance of a supply chain is affected by the performance of all actors in the chain and their ability to respond to changes (SEURING, 2009). The broader the system's boundary gets, the larger the number of structure components is.

Despite the number of stakeholders, it is also important to understand which perspective is used to define the supply chain performance. For example, a neo-classic economics perspective – which is based on "business-as-usual" – focuses only on financial efficiency. An environmental economics perspective attempts to allocate process externalities to the overall financial efficiency. Alternatively, an ecological economics perspective provides a broader standpoint that is closer to the sustainability goals than previous perspectives. It envisions material and energy flows efficiency instead of financial efficiency *per se*. In this holistic approach, the performance assessment has to considerer both social fairness of the process and the resulting externalities as well as the biophysical limitation of this process (DALY e FARLEY, 2010).

A drawback of employing the last perspective is the complexity associated to managing divergent stakeholders' values on how to assess, evaluate, and make decisions about structure components inter-relations. Buchholz *et al.* (2009) underline this high level of uncertainty and risk when discussing multi-criteria analysis for bioenergy systems assessments. According to them, the decision-making process is often guided by finding the low-hanging optimal solution based on strictly cost-benefit analysis instead of a more comprehensive study. Thereby, endorsing "business-as-usual" approaches and favoring the financial efficiency perspective as common ground for decision process. One reason for that could be that decisions are made at the specific business level, that is, each stakeholder may only have control of one single step in the chain and this limits its actions to efficiency at unit level (BUCHHOLZ, RAMETSEINER, *et al.*, 2009).

Whatever perspective is chosen, economic efficiency or sustainability goals, it reflects preferences and this will have a direct impact on parameters such as cost, quality, reliability, responsiveness, flexibility, and delivery (WEBER, CURRENT e BENTON, 1991). What these parameters contain in terms of information is likely to be affected by the purpose for what they will be used. The performance evaluation success relies on how able the parameters are to reflect performance according to the perspective chosen, and how these parameters can be aggregated into reasonable indicators.

These indicators were based on the *Supply Chain Operations Reference (SCOR®) model*, which helps to manage business problems through a standardized language, metrics, and business practices in order to improve supply chains' performance. (SUPPLY CHAIN COUNCIL, 2010).

We selected five parameter categories, which are commonly used on SCM, to be translated into evaluation elements and, then, incorporated into the performance assessment matrix. These parameter categories are:

- *Reliability:* this category evaluates the ability to perform tasks as expected. Its parameters focus on customer satisfaction and include: on-time delivery, right quantity of products, and their right quality;
- *Responsiveness:* it defines the process speed at which task is performed in order to meet customer satisfaction;
- *Agility:* this category is also focused on customer satisfaction. This parameter category includes focal link's flexibility and adaptability and measures its ability to adapt or to respond to external influences such as non-forecasted changes in demand patterns;
- *Asset:* it measures the focal link's ability to manage its assets such as inventory. Differently to the previous ones, this category focuses on financial efficiency; and
- *Cost:* it addresses the process costs related to labor, materials, transportation, etc. In short, this category covers the supply chain overheads. This last category is based as well on financial efficiency.

At first look, none of them reflect sustainability concerns. It is worth considering how they could be interpreted to incorporate sustainability dimensions in the analysis of supply chain performance. Taking for example the parameter *cost*, a neo-classic economics perspective will focus on production cost per ton of final product. An environmental economics perspective would consider the cost related to the size of production's ecological footprint per ton of final product, its impact on resource availability and/or climate change. Finally, an ecological economics perspective would consider costs related to health standards, labor conditions, environmental resilience, gender issues, local development, etc. per ton of final product as much as possible. Table 4 presents how these parameters are combined and translated into evaluation elements.

Table 4: Evaluation elements composition

Parameters	Evaluation Elements
Agility Cost Asset	Tactical (TEI)
Reliability Responsiveness Cost	Operational (OEI)
Reliability Responsiveness	Suppliers (SEI)
Responsiveness Cost Asset	Strategic (StEI)

Most of performance assessment strategies being used today establish performance indicators based strictly on financial efficiency and customer satisfaction (FLORENT e ZHEN, 2010). In this respect, this research cannot deny that these strategies already ratify the current need to evaluate a supply chain based on elements that promote and strengthen the chain inter-relations. Yet, meeting this new paradigm does not directly grant versatility to these strategies. We propose a strategy that allows broadening the performance evaluation structure and, at the same time, maintains the control during the assessment.

5.1 Presenting the Performance Assessment Strategy (PAS)

The Performance Assessment Strategy (PAS) is a helpful instrument to illustrate and optimize complex inter-relations within a system. The strategy itself can be basically described as a two-dimensional graphical representation of the performance assessment matrix. For that reason, the strategy reflects the same reasoning on its configuration. It displays axes containing quantitative data based on evaluation elements, which are combined to match specific competence (e.g., coordination, understanding, design, and improvement). Each specific competence is placed in a quadrant. Each quadrant presents the focal link's capability on responding reactively, proactively, or both to impacts and uncertainties. For example, the quadrant representing the coordination competence is classified as a reactive initiative because this competence describes focal link's ability to respond or adjust to short-term requirements such as meeting an increased demand for a given energy carrier. In order to meet this increment, focal link needs to coordinate its capacity flexibility and financial flow (e.g., tactical evaluation). At the same time, it requires measuring its ability to avoid losses and its compliance to planned production schedule (e.g., operational evaluation). As a result, the coordination quadrant is a combination of Operational Evaluation Indicator and Tactical Evaluation Indicator. The remaining quadrants follow the equal rationale with their specific evaluation elements.

This type of graphical representation is well suited for illustrating outliers and commonality in such way that a common pattern or behavior would appear in the same range. On the other hand, outliers or patterns deviations could spike and range abruptly. In the case of PAS, data plotted closer to the center indicates higher performance. Likewise, the lower the performance is, the further from the center the data will be plotted. Figure 9 illustrates how the strategy can be used to analyze a focal link that in this case corresponds to a hypothetic company.

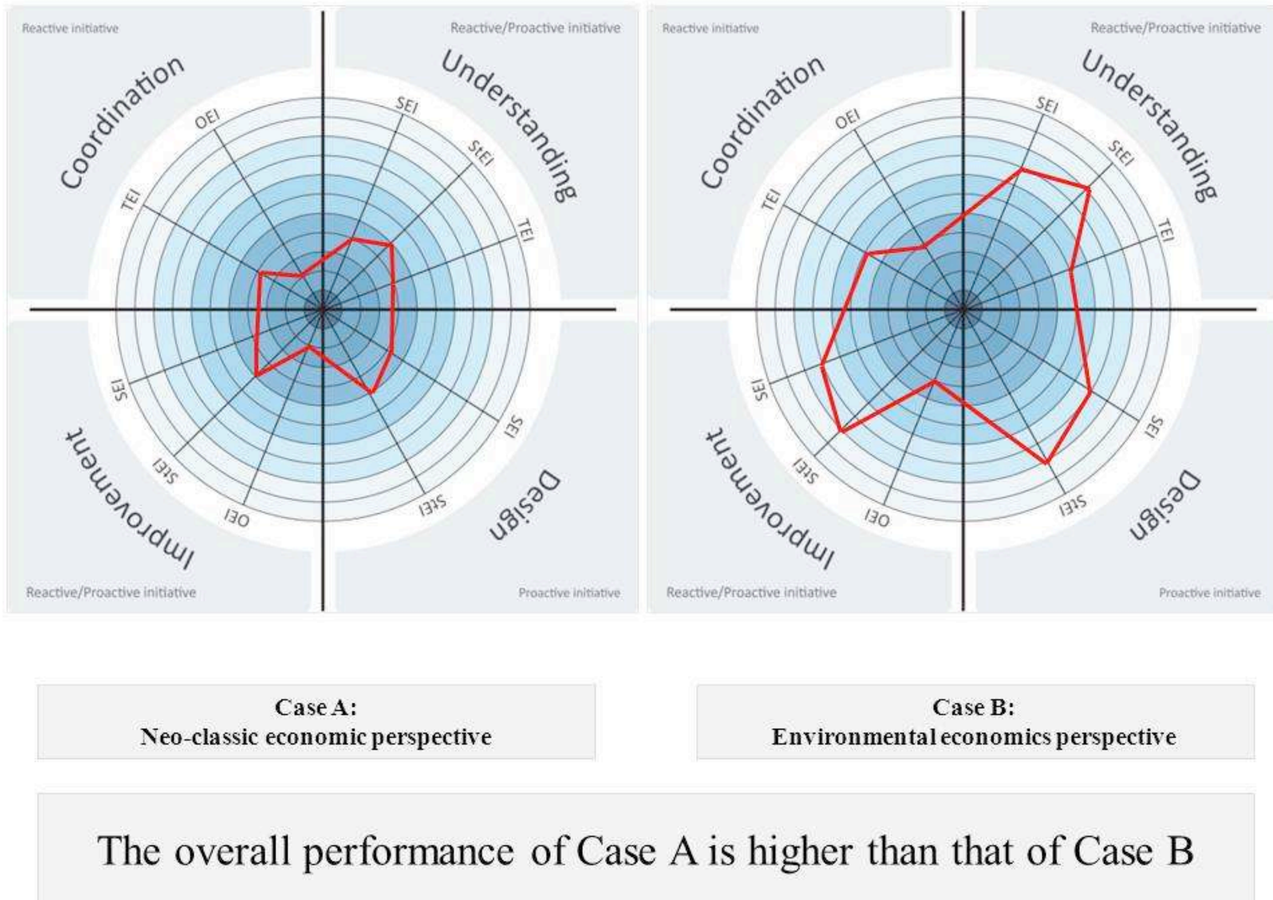

Figure 9: Hypothetical use of PAS

In Case A, a given Company X's performance is assessed using a neo-classic economics perspective. The coordination quadrant shows that Company X is able to comply with unplanned production demands without disturbing its daily routines because it has a high coordination performance. Therefore, X is capable to respond or adjust its production operation to short-term requirements. This means that X is highly reactive and it presents not only a flexible operational capacity but also a flexible financial flow. The understanding quadrant shows that Company X is aware of its suppliers' capacities on meeting its increasing raw material demand if it is needed. This means that X understands not only its supplier responsiveness and reliability but also the current market requirements. The improvement quadrant presents that Company X is aware of processes or activities within its operation that need to be enhanced in order to upgrade its final product. This means that X understands how much such upgrading will cost not only to improve its product quality but also to expand its market share. Lastly, the design quadrant shows that Company X is able to mobilize its suppliers in connection to new market specifications but it has not clear long-term goals when it comes to design products for future markets. This means that X is more reactive than proactive when it comes to planning its operational capacity and financial flow. In short, the chart shows that X's is able to respond in short-term to impacts on its supply chain. Its overall supply chain management can also reduce uncertainties about potential impacts related to future market prices and, to a lesser extent, perceive limitations of its suppliers. In this case, PAS shows which areas the Company X should select to improve its overall performance.

In Case B, the same Company X assesses its performance using a different perspective based on environmental economics. Now, the chart shows that X's overall performance is lower than that of previous perspective, which was based on "business-as-usual" and focused only on financial efficiency. The same company presents a lower performance because this new assessment accounts externalities related to environmental impacts of its material and energy flows. Hence, PAS is a reflection of management choices. It can assess performance, whether that means rigorously analyzing financial performance (e.g., Case A) or adding externalities accountability to the analysis of material and energy flows (e.g., Case B).

PAS does not favor a specific economic view as common ground for decision-making processes within the supply chain. Instead, PAS allows not only broadening the performance evaluation structure but also replicating and comparing the network relationships. In this context, PAS provides a methodological development that could be useful for improving supply chain management practices in complex systems.

5.2 Answering the research question

At the beginning this research raised the following question: *How can decision-makers push the boundaries of supply chain management in order to enhance its sustainability?*

One step closer to the answer is to create assessment strategies able to measure sustainability in daily practices and to translate these data on conditions and trends of sustainable development within the network into reliable and straightforward information. In this perspective, PAS is pushing the boundaries of our understanding of supply chain management by creating an entirely new method and combining standard instruments in a novel fashion.

In order to clarify whether PAS can or not intervene in a system and push its boundaries, this research crosschecked the strategy with Meadows' leverage points. Meadows (1999) states that complex systems (i.e., bioenergy systems) are by definition intricate and, therefore, it is dangerous to generalize about them. As a result, finding leverage points or places to intervene in a system cannot be an intuitive process because they are not easily accessible. Her work confirms that the higher the leverage point's effectiveness, the more the systems resist its influence to change patterns (MEADOWS, 1999).

Meadows (1999) describes 12 leverage points, which are presented in an increasing order of effectiveness. However, it is important to address that every point may have exceptions that can move up or down its degree of leverage.

Parameters: they are described as the points of lowest leverage effects in the system. However, they are easily perceived among all other leverage points. On the one hand, they rarely change behaviors and, therefore, have little long-term effect. On the other hand, they can provide a snapshot of the situation. The proposed strategy not only organizes these parameters but also classifies them as reactive or proactive initiatives in order to provide a clearer snapshot of the situation. PAS covers this leverage point.

Stock Size: the size of the stock can act as a buffer because when the stock amount is much higher than the potential amount of inflows or outflows it can stabilize a system. Three out of four competence dimensions of the proposed strategy consider stock size in the analysis. PAS covers this leverage point.

Network Structure: a network structure of the system has enormous impact on operations. Structural changes are difficult and often prohibitively expensive. Understanding the structure can define operational limitations and bottlenecks within the system. One of the main objectives of the proposed strategy is to map the operational limitations and to identify bottlenecks in the network structure. PAS covers this leverage point.

Rate of system's oscillations: receiving delayed information about what the system state is can be considered one of the most common causes of oscillations in a system. The proposed strategy reflects this leverage point because its analysis of the network considers, for example, the time taken for a particular good's price to adjust to a supply-demand imbalance. PAS covers this leverage point.

"Strength" of Negative Loops: this leverage point represents the system's ability to keep its stock at/or near to balance. A negative feedback loop is self-correcting. Thus, it depends on the accuracy of monitoring, speed to react, and power of response to regulate the system's dynamics. The previously mentioned parameters are important to understand the direction and size of these corrective measures. The proposed strategy can help to identify them within the network. For example, the proposed strategy can recognize price variation and its effects on keeping supply and demand in balance. The more the price information between producers and consumers is kept clear, the more efficiently the network will flow. PAS covers this leverage point.

"Driving" Positive Loops: a positive feedback loop is self-reinforcing, which means the more it works, the more it gains force to work more. Thus, they are sources of system's growth, expansion, and collapse. Slowing or driving its momentum is generally a powerful leverage point and more preferable than reinforcing negative feedback loops. For example soil erosion caused by high wood demand, the higher the consumption of forest-biomass is, the less vegetation to soften rain and run-offs exists and the more the soil erodes. The proposed strategy can help to identify these positive loops. PAS covers this leverage point. PAS covers this leverage point.

Structure of Information Flows: delivering information structures can be a powerful intervention and often much easier and cheaper than building or restoring a physical infrastructure. The proposed strategy tracks information flows within the network and identifies missing links. PAS covers this leverage point.

System's Rules: the rules of the system define its boundaries and its dynamics within the network of stakeholders. The proposed strategy attempts to identify all structure components within the chain under examination. This is crucial step for the effectiveness of the strategy because the overall performance of a supply chain is directly affected by the performance of all structure components in the chain and their ability to respond to changes and to follow rules. PAS covers this leverage point.

Self-organize System Structure: this leverage point is related to changing any aspect of the previously listed points. Thus, self-organization means adding completely new physical structures, creating new institutional capacities, adding new negative or positive loops, and making new rules. It is related to system's resilience. An evolving system can survive nearly any change by changing itself. The proposed strategy can map network's combination in different scenarios but cannot forecast self-organized system structures. PAS partially covers this leverage point.

System's Goals: the system's goals are survival, resilience, differentiation, evolution, etc. This is a superior leverage point because everything mentioned beforehand in the list will be shaped to achieve that goal. Therefore, this leverage point also shapes the proposed strategy and it can only assess the performance in connection to that goal. PAS partially covers this leverage point.

Current System's Mindset: mindset defines societal shared ideas that everyone already knows. Thus, the proposed strategy can provide a snapshot of the paradigm and point out its anomalies and failures. PAS partially covers this leverage point.

The power to transcend paradigms: the highest leverage point is to realize that every paradigm is limited. If no paradigm is right, one can choose whatever paradigm one will use to achieve his purpose. PAS does not cover this leverage point.

Although the proposed assessment strategy presents a theoretical potential to intervene in complex systems and push their boundaries, it is important to address that PAS's effectiveness is guided by the perspective being used to define the performance of a given supply chain. Choosing a neo-classic economics perspective over an environmental economics perspective or an ecological economics perspective cannot only move up or down the degree of leverage covered but also rearrange the status of the leverage point itself from being described from "*covered*" to "*not covered*". This flexibility of choosing the perspective provides versatility to the strategy and reassures its holistic approach but it can be misused to justify the "business as usual" approach over more sustainable initiatives.

5.3 Concluding remarks

Supply chains are important causal links between human activities and environmental changes, which confirms the high relevance of Supply Chain Management as a strategy to intervene in the current development model and foster the implementation of sustainable development. Identifying this intervention as a sustainable supply chain means that its management should take into account not only the economic efficiency but also the social fairness of the production process and its biophysical limitation.

In order to foster supply chains to become more sustainable, it is necessary to not only operationalize the sustainability concept within the network performance but also to be able of verifying this very performance in daily practices. Hence, it is necessary to translate complex realities of supply chains' performance into a limited sequence of familiar symbols or reference marks such as *reliability*, *responsiveness*, *agility*, *asset*, and *cost*, which are common parameter categories in SCM. Furthermore, performance assessment has a more substantial role than merely quantification and accounting actions, especially when it comes to assessing the performance of bioenergy supply chains. In this case, it has not only to mobilize additional biomass resources for bioenergy expansion but also to avoid or reduce negative impacts of this expansion.

From what has been presented so far, the Performance Assessment Strategy (PAS) presents a strong theoretical framework with many potential applications. In addition, the concept of focal link provides an opportunity to use the strategy in a very diverse way. Meaning, PAS can be applied not only on a single company level but also on more complex networks such as an organization group, an industrial segment or a productive sector. Regardless of whether a neo-classic economics perspective or a more broaden perspective aligned with the sustainability concept is used as performance target, the proposed strategy can be an effective instrument for understanding not only network flows but also focal link's management weaknesses and strengths. As a result, PAS is a useful instrument for decision-making processes and it can be used by a variety of stakeholders, from management staff to policymakers.

5.3.1 *Future research*

Follow-up research is necessary to validate PAS's applicability in real-life context. This next research step will happen through a case study because it can provide stronger evidence in support of not only the strategy's technical validity but also its reliability (YIN, 2009). The idea is to conduct three case studies. The first is going to be conducted in Sweden, the second in Brazil and the third in an African country, which is not yet selected. The idea behind using different case studies is to synchronize the strategy's processes of evaluation and validation. Although this method can oversimplify the problems, it builds knowledge and validates gathered information through site-specific evidence provided by a variety of sources (STAKE, 1995; SIMONS, 2009).

This future research is going to be developed in the Division of Energy and Climate Studies, Department of Energy Technology at KTH School of Industrial Engineering and Management, Sweden.

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