Economic valuation of environmental damage: the case of nonwoven fabric in Denmark

Romain Sacchi

Energy and Planning department

Aalborg University

A thesis submitted for the M. Sc. degree of

Environmental Management and Sustainability Sciences

June 2012

Abstract

Hydrocarbon-based substances represent 80% of today's fuels production. Energetically dense and easy to handle, their sub-products, *e.g.* plastics, rubber, oil, are present in most of industrial applications. Yet, its over-use is associated with social and environmental impacts. They often lead to public goods degradation, which enhances environmental endpoint issues: global warming, human health impairment, biodiversity loss and others. These damages are mostly omitted by actual market mechanisms: they are external costs, borne by the society as a whole.

Ecological Economics gives a conceptual framework that stresses the need for assessing and internalizing these externalities. *Industrial Ecology* gives means to assess them. And economic valuation studies give the data to monetize them. Combined, these techniques may be used to analyse environmental policy efficiency and design.

This study details the Danish manufacture of 1 ton of hydrocarbons-based nonwoven fabric, taken as a functional unit. The environmental impacts during its Cradle-to-Gate assembly are assessed through two robust *Industrial Ecology*'s tools: Life Cycle Assessment and Input-Output analysis with Environmental Accounts.

Based on EU's economic valuation methods for environmental degradation, the impacts are monetized in terms of damage and avoidance costs. Marginal costs are derived for each impact category considered: climate change, human health impairment, agricultural and material loss.

Results show an external marginal cost interval of 197–344€ per functional unit produced in 2011. The comparison of this estimate with Denmark environmental fiscal instruments reveals that these externalities are only partially covered (around 217 €).

Based on the results, Denmark environmental taxes system is assessed: while the overall taxation level remains high, some specific emissions-related degradation do not, or poorly, have any tax counterpart. Additionally, suggestion are made to improve the policy design.

Acknowledgements

This document is the final achievement of a Master programme supported by the Department of Development and Planning of Aalborg University. The underlying work started in January 2012 and ended on the 7th of June, 2011.

The research content is dealing specifically with the economic valuation of environmental degradation through LCA and IO-EA.

In that regard, I would like to seize this opportunity to acknowledge the contributions of some persons along this undertaking.

This work would not have been possible without the relevant support of Thomas Broch-Nielsen, Senior Scientist at Fibertex Personal Care, who provided me with inestimable inputs for building up life cycle inventories.

Additionally, the kind but firm guidance of Søren Lokke, Associate Professor at the Department of Development and Planning at Aalborg University, has been of a great help in the realisation of the research content.

Finally, I would like to express my gratitude to Matthew Cashmore, Associate Professor and EMSS degree 4th semester coordinator at Aalborg University for his pertinent remarks regarding the redaction of this document.

I am very grateful for all of your inputs.

Document details

About the author

Name – Romain Sacchi (r_s@me.com)
Degree year – 2010-2012
Programme – Environmental Management and Sustainability Sciences
Department – Department of Energy and Planning
University – Aalborg University

About the document

Title – Economic valuation of environmental damage: the case of nonwoven fabric in Denmark
Creation date – 31/03/2012
Hand-in date – 07/06/2012
Tags – Ecological economics, Industrial ecology, nonwoven, Denmark, life cycle assessment, input-output, NAMEA
Engine – TEX
Producer – pdfLATEX
Language – British english
Approx. words count (excl. Abstract, Acknowledgement, Document details, Contents, Glossary, References and Appendixes) – 9 850

Contents

List of Figures

List of Tables

Glossary

Abatement cost Usually employed in pollution reduction economic analysis, the marginal abatement cost refers to the costs resulting from reducing the pollution level of one grade down. Modern economics theory states that ideal pollution reduction efforts must be engaged to the point where marginal abatement cost equals the marginal social benefit.

Biosphere It is a living and study area of a wide thermodynamic open system to external influences, which derives most of its energy from sunlight via photosynthesis. The complex mechanisms of auto-maintenance and sustainability of the biosphere sets up each year, into chemical energy, some 500 billion of billion calories or nearly 10 times more than what is consumed by all forms of human industry. From a more biological perspective, the biosphere encompasses the lithosphere, the hydrosphere and a part of the atmosphere.

CFA Carbon Footprint Analysis - it is considered a subset of Life Cycle Assessment as it focuses solely on a single impact category: Global Warming. Indeed, although it observes the same methodology, steps and structure as a Life Cycle Assessment, the Carbon Footprint Analysis looks at environmental damages resulting directly from the release of greenhouse gases throughout the product life cycle stages. The assessment is compiled in a single score midpoint indicator: a quantity of CO_2 *eq.* gases. It may be used as a basis for comparison with other product systems and interpreted as the product or service potential contribution to the planet global warming.

CHP Refers to the use of a steam-powered plant to simultaneously generate both electricity and useful heat. A CHP plant captures some or all of the heat produced by the steam process and transforms it into other useful and distributable forms, such as heat injected in the district heating system, or electricity released in the national grid.

Cradle-to-Gate Refers to the life cycle of a product. It designates the very beginning of the conceptual phase of a product, the first step of its life cycle, to its full manufacture at the factory plant: the cradle, where the product is born by extracting raw materials and capturing energy, down to the gate, where the product is manufactured and ready to be distributed to end-users. In this case, the distribution, use and disposal phases of the product life cycle are omitted.

Damocles-type risk Damocles-type risks refer to large and catastrophic events with a very low probability of occurrence. The inclusion of such risks in costs evaluation, through expected value, still remains difficult in environmental damage valuation methods, as the frequency of such events does not allow an empirical basis for calculation. Additionally, very high uncertainties regarding risk aversion and the extent of damages make the cost valuation results too broad to be useful. Hence, nuclear incidents risk, among others, is usually not included in economic valuation methods.

EDP Environmental Production Declaration - consists in a set of documents stating on the environmental performances of one or several products, encompassing a certain scope explicitly defined to the audience. Although there are no specifications concerning the writing of such documents, international standards norms ISO 14025 may be followed to ensure transparency and quality throughout the report. Declarations are often peer reviewed and are proceeded voluntarily, often perceived as a mark of commitment to preserving the environment and transparency to products end- users.

Endpoint indicator Quantitative or qualitative compilation of results given by an impact assessment method within the framework of a Life Cycle Assessment. It aims at supporting the decision-making process by reducing the complexity of the model studied down to several impact categories which notions are easier to grasp. Endpoint indicators lead to the generation of results further away from the model original complexity by boiling it down to few more general impact categories, making it easier to visualise the rough picture of the product system-related environmental issues. Sometimes subject to criticism, too simplistic endpoint indicators inevitably loose in accuracy and scientific validity.

EPR Extended Producer Responsibility - It is usually a set of economic incentives to encourage manufacturers to design environmentally friendly products by holding producers responsible for the environmental costs of their products end of life. It requires manufacturers to internalize the cost of recycling the product price. EPR can take the form of recycling, redemption or a recycling program. In this way, EPR shifts responsibility for waste management by the government to the private sector.

GHG Greenhouse gases - various types of gases observing the physical property of absorbing and re-emitting radiation coming from the infrared radiation wavelength range. If these gases form a layer in the upper atmosphere, between solar radiations and the Earth surface, a part of the solar radiations are prevented from being reflected back into space. Trapped within the atmosphere, the solar energy output is limited. It provokes a so-called greenhouse effect, leading to the progressive warming of the planet.

Industrial Ecology It is the study of material and energy flows through industrial systems. The human-made economy can be modeled as a web of industrial entities that extract the planets material and energy resources and to transform them into products which are then exchanged on markets to meet the needs of humanity. Industrial ecology seeks to quantify and report the flows of materials and describe industrial processes observed in the modern society. Industrial ecologists are often concerned about the impacts that industrial activities on the environment, with the use of the worlds supply of natural resources, and problems with waste disposal. Industrial ecology is a young but increasingly multidisciplinary research that combines aspects of engineering, economics, sociology, natural sciences and toxicology.

IPP Integrated Product Policy - it is a set of policies initiated by the European Union which aims is to reduce the environmental degradation of the industry by focusing on the life cycle of the products. It advocates the shift towards a services-oriented economy and a better handling of products in their end-of-life phase. Although strongly criticized for its lack of completeness to tackle the problem of sustainability notably in regards to missing policies concerning the reduction of unnecessary consumption , it is the most advanced policy framework today in regards to the sustainable development of industries.

ISO 14040:44 presents the principles and a framework for conducting Life Cycle Assessment. It defines the structure of a Life Cycle Assessment study as well as the content, explanations, clarity and transparency that must appear in the report. While ISO 14040 focuses more on establishing the reasons, concepts and principles of a Life Cycle Assessment, ISO 14044 is mainly giving the guidelines and requirements when conducting and reporting the analysis results.

LCA Life Cycle Assessment - it is a tool to evaluate environmental impacts associated with all of a product life cycle stages. It allows a complete representation of the necessary economy-environment interactions that are involved in the manufacture of a product by compiling material and energy flows, evaluating the potential environmental harm of these flows and interpreting the results to draw conclusions on the product soundness. It is perceived as a strong tool supporting the Integrated Product Policy in offering a transparent, comprehensive and scientifically-recognized way to guide customers in their consumption choices towards greener products.

LCI Life Cycle Inventory - an analysis that consists in creating an inventory of material and energy flows to and from the nature to the product system studied. To develop the inventory, a flow model of the technical system, such as a Mass Flow Analysis, is built using data on inputs and outputs. The input and output necessary for the construction of the model are collected for all activities within the system boundary, including the supply chain (called the *technosphere* inputs). Therefore, LCI is considered as a subset of LCA since it observes the same methodology and uses the same tools. However, an LCI does not assess the environmental consequences implied by these material and energy flows nor it gives any interpretation based on this assessment. Simply put, it stops two steps earlier.

MFA Mass Flow Accounting; Materials flow analysis is a method/tool to quantify the flows and stocks of materials and energy exchanges between a system and its environment. The system studied becomes defines by the flows of material and energy coming in and out and/or accumulates within. It is, with Life Cycle Assessment one of the pillar tools of *Industrial Ecology* and is very accurate in defining physical consequences of human-nature interactions.

Midpoint indicator Quantitative or qualitative compilation of results given by an impact assessment method within the framework of a Life Cycle Assessment. It aims at supporting the decision-making process by reducing the complexity of the model studied down to several impact categories which notions are easier to grasp. Unlike endpoint indicators, midpoint indicators relate to impact categories of a lesser extent, giving less room to value choices but highlighting more specific and complex issues.

Pythias-type risk Pythias-type risks are characterized by uncertainty in regards to their frequency of occurrence and to the extent of their damages. Very difficult to ass, it is however preferable to take precautionary measures to prevent the damage from occurring. However, they are usually not included in environmental damage economic valuation methods.

Risk aversion Risk aversion is one of the foremost principles found in economics. It is highlighted by Daniel Bernoulli, there are 300 years. It led to the economic concept of utility and the notion of market risk premium, which helped to better understand the equilibrium price and yield, and discuss their mathematical modeling.

Second-order energy analysis A second-order energy analysis regarding Life Cycle Assessment differs from a first-order analysis in which it encompasses not only the production and transport stages in terms of material and energy needs, to achieve a functional unit, but also the different life-cycles of the processes needed to achieve the function unit. This means, it includes the respective life-cycles of the transport, the production and the other stages of the life-cycle of the functional unit: design, distribution, use and disposal. In the same way, it differs from a third-order energy analysis in which it does not account for the material and energy needs related to the life-cycle stages of the capital equipment present in every life-cycle stages of the functional unit. However, if a third-order analysis accounts for them, it usually only does for the production stage of the capital equipment, while the other stages are left out.

Technosphere The technosphere must be here understood as the concept created by Vladimir Vernadsky, which designates the part of the physical environment affected by anthropogenic changes, that is to say, of human origin.

WTP Willingness-To-Pay - It is a concept of consumer theory in microeconomics. It means the amount a given consumer is willing to pay to acquire and consume a good or service. This tendency derives from the consumer's utility function. In Ecological Economics and Ecosystems services studies, it is desirable to know the individuals' willingness to pay for an assessment of the importance they attach to public and ecosystem services or natural capital.

1

Introduction

Hydrocarbons are the results of millions years of organic material decay between sedimentary rocky layers. The sequestration of hydrogen, but most importantly carbon, in the Earth's crust allowed favourable conditions for life as it is known today.

If the *de-sequestration* and combustion of hydrocarbons brought in important economic benefits, serious concerns are expressed towards environmental mechanisms it may enhance. Issues stemming from the massive use of hydrocarbons are numerous and involve complex direct and indirect mechanisms. Two main concerns are predominant. A first technical concern is the shortage of a valuable resource for processing chemicals in the future. The second environmental concern is broader [Daly(1994)]:

- The extraction of hydrocarbons enhances mechanisms leading to landscape degradation, coastline retreat, biodiversity loss and freshwater contamination,
- The combustion and processing of hydrocarbons accentuates the mechanism leading to *global warming*, via the release of GHG[1], human life impairment and biodiversity and material loss.

The resulting environmental damages are significant. They affect the *sustainable* state of the biosphere, which may be defined based on the German Bundestag's Study Commission [Enquete-Kommission(1994)]:

1. On the long term, the use of a resource should not exceed its replenishment rate or the substitution rate of all its functions,
2. On the long term, the emission of substances should not exceed the treatment or assimilative capacity of the environmental medium,

[1]Greenhouse gases. For a definition, see the Glossary at page xii.

3. Environmentally hazardous and dangerous human activities should be avoided,

4. A time ratio should be respected between any anthropogenic interferences with the environment and the time required for the environment to engage in re-stabilisation and reaction.

According to the Millennium Ecosystem Assessment[Assessment(2005)], this sustainable state is guaranteed by the Earth's *ecosystems services*, which are:

- *provisioning services* (food, fibres, fuel, water)
- *cultural services* (spiritual, religious and aesthetic wellbeing)
- *supporting services* (soil formation, photosynthesis, water cycling)
- *regulating services* (air quality regulation, hydrological regulation)

Thus, environmental mechanisms involved in hydrocarbons extraction and combustion admittedly perturb the functioning of *ecosystems services* and compromise the *sustainable state* of the biosphere. It results in harmful endpoint[1] consequences on the biosphere, but also on the socio-economic sphere: sea-level rise, human health impairment through air quality reduction, social unrest, propagation of diseases, loss in agricultural productivity, extreme weather events, floods, freshwater scarcity,... [IPCC(2007)]

The propagation of these environmental impacts are the result of the market inability to entirely reflect economy-environment interactions in terms of costs. Hence, environmental impacts are costs which remain external to the market, mainly because it affects non-market goods and services. Should these costs be assessed and considered in market transactions, it is believed this would set a different output in terms of production and pollution levels.

Why and how to reveal environmental externalities?

To illustrate this argument, this study first develops the concept of environmental externalities through the framework of *Ecological Economics*. It highlights the fact that certain products, such as nonwoven fabric and other hydrocarbons derivates, are produced in large quantities in our society while it gravely impacts human life and other ecosystems' assets. It stresses the need to identify these externalities and integrate them so as to change consumers and producers'

[1]Endpoint environmental indicator is a damage-oriented indicator for wide impact categories, *e.g.* eco-toxicity. Opposed to midpoint indicators. For a definition, see the Glossary at page xii.

behaviours and reduce the proliferation of harmful products.

Second, the need for an *interdisciplinary* science concerned with industrial applications is expressed. Such framework would ease the identification of harmful *product system*-environment interactions. This support is given by *Industrial Ecology*'s[1] philosophy and its closed industrial systems concept. It promotes a symbiotic approach with the larger systems industries are embedded in. *Industrial Ecology* proposes guidelines to consider physical constraints, an optimal use of resources and the impact of operations on the environment when manufacturing a product. Additionally, *Industrial Ecology* provides with tools to assess the *maturity* and the *sustainability* of a product system. They help to assess how well a product system interacts with the environmental sphere all along the product *materialisation-dematerialisation* cycle. Two of the most eminent tools are LCA[2] and IO-EA[3]. They reveal and quantify environmental impacts occurring within the Supply Chain of a good or service and set a solid base for their environmental performances assessment.

How to value environmental externalities?

Once the environmental impacts of a product system are assessed and quantified, they need to be expressed in a common measurement unit so as to ease their understanding and integration into the economic system. A way of effectively reaching this goal, used by most of the externalities economic valuation methods, is to identify the *bottom-up* relation between the pollution source and the endpoint receptors on which damage is inflicted and *monetize* these impacts: damage and avoidance costs. They can be based on individuals' preferences or experts and political judgements, through direct and indirect costing methods, involving market and non-market values. These figures, which can be expressed as total, average or marginal costs, are widely conditioned by individuals' preferences in regards to the future and their aversion for risk, by the in/exclusion of extreme environmental events and various other factors, that bring non-negligible uncertainties to the results. However, solid and standardised methods are now available and already in use in several policy-making institutions.

[1]Industrial ecology is a young but increasingly multidisciplinary research that combines aspects of engineering, economics, sociology, natural sciences and toxicology. For a definition, see the Glossary at page xii.

[2]Life Cycle Assessment. For a definition, see the Glossary at page xii.

[3]Input-Output analysis with Environmental Accounts. For a definition, see the Glossary at page xii.

How to internalize environmental externalities?

In order to fully reveal these environmental hidden costs and affect stakeholders' preferences in that regard, ways to *internalize* externalities are presented. This work mainly distinguishes two categories: the direct intervention on market prices (*e.g.* eco-taxes, Producer/User Pay Principle, emissions trading permits) or the indirect negotiation on pollution reduction (*e.g.* international pollution agreements, environmental standards, pollution quotas, de-sulphurisation units).

The case of nonwoven production in Denmark

To support this argument and show the need for a well designed environmental policy, the example of hydrocarbons-based nonwoven fabric manufacture in Denmark is analysed. First, a short description of the nonwoven fabric market is given. Second, a Denmark representative Cradle-to-Gate[1] life cycle of 1 ton of nonwoven fabric is analysed using the two mentioned tools: LCA and IO-EA. While these two methods work differently and both present advantages and disadvantages, summing them up is thought to allow a broader but accurate analysis of the product system. The significant environmental impacts are identified and assessed.

Using up-to-date European economic valuation methods, the environmental impacts and their direct, indirect and structural consequences on endpoint receptors are evaluated. The resources that would be needed to reverse the damages and/or to compensate for them are estimated.

Finally, these estimates are compared with current national compensation services (taxes) to reveal where and when externalities are, can or need to be *internalized* along the nonwoven fabric Supply Chain.
Suggestions are drawn in regards to environmental policy in Denmark, to develop symbiotic and sustainable businesses that support the *economy-environment* decoupling objective.

[1] Analysis where the distribution, use and disposal phases of the product life cycle are omitted. For a definition, see the Glossary at page xii.

2

Beyond the economy

This chapter defines the theoretical framework supporting the research core ideas.
Unaccounted environmental degradation occurs in the value chain of hydrocarbons-based chemicals and fuels. It reveals flaws caused by the opacity of information within stakeholders transactions.

If markets were to regulate according to producers and consumers' rationale only, they would certainly not lead to Pareto's optimal outputs. Indeed, markets are primarily driven by stakeholders' preferences. Yet, stakeholders are often misinformed about conditions in which products are manufactured. It results in price signals that do not reflect the entirety of the costs experienced along the Supply Chain. Unaccounted costs do not show in the demand-offer curves and become external to the economy. As [Ayres and Kneese(1969)] mentioned, there are three types of economy-environment interactions that do not have any economic pricing:

- the use of *common goods and resources* for private purposes, *e.g.* air, streams, lakes, and the ocean,
- the use of the environment digestive capacity of waste and polluting substances for private purposes,
- and the use of unwanted materials in a production process, *e.g.* diluents and pollutants.

Hence, this leads to a situation where it becomes

> "economically efficient to behave ecologically inefficiently" [Binswanger(1993)]

This axiom stems from the *Ecological Economics*'s fundamental idea that current economics fail to comprehend the progression of human-made systems over the finite biosphere. [Georgescu-R(1971), Boulding(1950), Ayres and Kneese(1969), Daly(1968)] were some of the economists to highlight opacity of information on markets and among stakeholders. They criticised how modern economics consider resources infinite, how natural services use is disregarded, how the market absence for non-value goods lead to overexploitation, how common property rights drives to the Hardin's *tragedy of the commons*, and finally, how ignoring physical, biological, chemical and ecological dimensions lead to discard deep-rooted social and environmental impacts.

The next sections deal first with *Ecological Economics*'s multidimensional considerations of sub-systems interconnectedness.
Second, the description of *Ecological Economics* axioms highlights the importance of *internalizing* damages occurring during the manufacture of a product, linking up the economic and environmental spheres. A third section stresses that the assessment of environmental damages may be approached through *Industrial Ecology* methods, by capturing the overall *life cycle* of the product or service considered. Finally, European Commission's economic valuation methods of environmental degradation are proposed for assessing damage and avoidance costs associated with known environmental impacts.

2.1 Ecological Economics and market failures

Society's welfare maximisation through markets has never been considered as anything else as the pure result of a Pareto optimal allocation of market goods, and certainly not as a possible long-term coexistence of the environmental, social and economic spheres. [Kronenberg(2007)]

The narrow focus of neoclassical economics led to the emergence of a wider scope of analysis: *Ecological Economics*. This multi-disciplinary field encompasses moral, ethical, economical and environmental aspects and offers a solid framework for macro- and microeconomic decision- and policy-making.

According to [Kronenberg(2007)], *Ecological Economics* encompasses three levels of considerations, as seen in Figure 2.1:

1. *Primary considerations*: it refers to "real-world" constraints guided by the laws of physics, chemistry, ecology and biology.

2. *Secondary considerations*: assess how limitations found in the primary considerations affect the society's welfare in regards to economic and environmental outputs, *e.g.* products and pollution.

3. *Tertiary considerations*: shaped by limitations and assumptions

present in the two first considerations levels, this third level evaluates the overall picture given by the production of goods or services. It returns an optimal set of outputs to operate a Pareto move, where none of the social, environmental and economical stakeholders' welfare are, at least, worse-off.

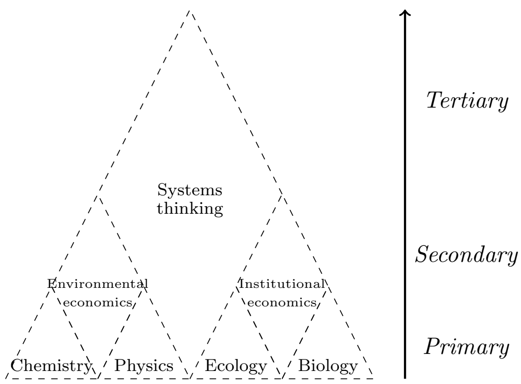

Figure 2.1: *Ecological Economics* considerations. *Source: Kronenberg, 2007*

Hence, analysing a configuration based on *Ecological Economics* grounds allows to draw conclusions through a sustainable framework which includes an economic, environmental and social dimension. It depicts welfare moves beyond a pure economic scope, since, unlike modern economics, it:

- acknowledges the finiteness and conservation of energy and mass as well as the energy quality degradation over time, *i.e.* First and Second Laws of Thermodynamics,
- considers the materialisation-dematerialisation pattern of a product: its *life cycle*,
- values not the product itself, but the utility derived from its function,
- as Environmental Economics, forbids the systematic substitution of natural capital by manmade capital, *i.e. strong sustainability*,
- reckons a finite Earth carrying capacity,
- and finally, provides a support for assessing the use and degradation of public goods and services where traditional markets are missing.

Figure 2.2 illustrates the economic system expansion seen by Ecological economists.
This system relies on energy and material inputs provided by the biosphere, through solar radiation and natural resources. The *joint-production* of waste heat and material follows the rules of thermodynamics – increase in entropy – while natural capital has an equal importance in the production function with human, equipment and social capital. Production of waste and the resulting environmental impacts have negative economic consequences, but affect the overall well-being too.

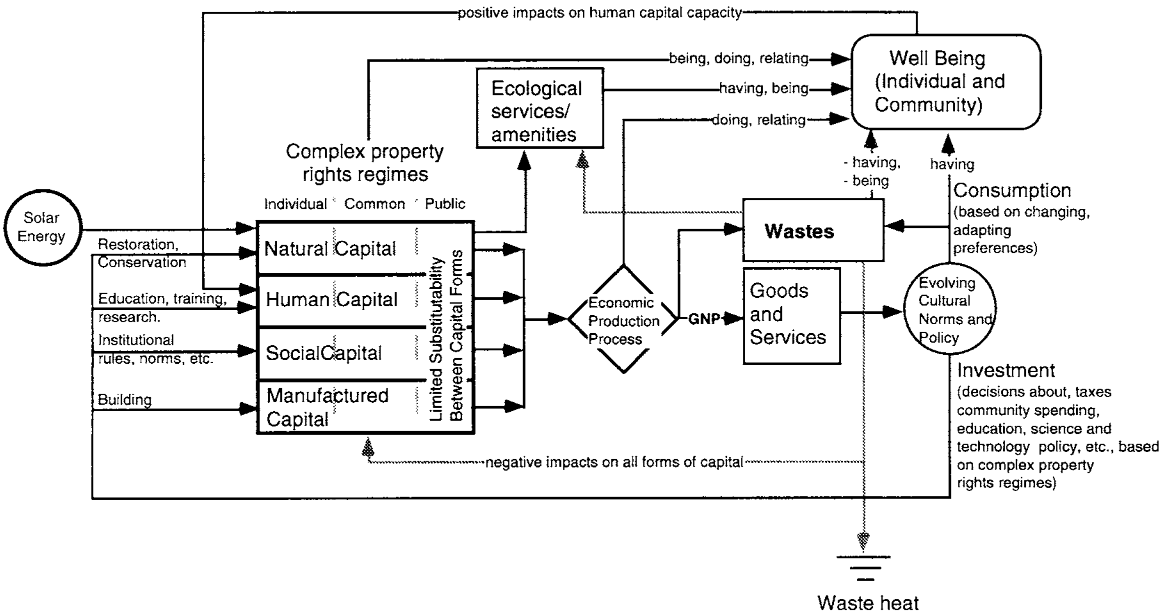

Figure 2.2: The *Ecological Economics* expanded model. *Source: Constanza, 2001*

2.1.1 Non-market goods and services

Ecological Economics emphasises also the need to remunerate the use of ecosystems services to compensate for the degradation inflicted on endpoint receptors – humans, fauna, flora – or to finance possible adaptive measures when the damage is irreversible. The process of communicating unaccounted impacts inflicted upon non-rival and non-excludable public goods – *i.e.* ecosystem services – in the product value chain is called *internalization of externalities.*

History in economics has shown two ways of internalizing external costs:

1. through a direct intervention on market prices. This can be achieved in several ways: pollution trading permits, *pigouvian* taxes, etc.

2. through an indirect legal action: environmental standards, pollution quotas, political and societal pollution reduction targets, etc.

An abundant literature describes ways of internalizing external costs. While the Coase theorem[1] may be efficient when private property rights are well defined, this cannot apply to public goods, such as ecosystem services.

[1] R. Coase, *The Problem of Social Cost*, 1960: in presence of externalities, if transaction costs are minimal and property rights are well defined, bargaining between the "polluter" and the stakeholder bearing the cost will result in an efficient allocation of resources.

A *pigouvian* tax following the "Polluter Pays Principle" or the "User Pays Principle" is usually preferred. In this case, whoever bears the internalized cost, a new output that satisfies both producers and consumers will be set. This new output will reflect the stakeholders' preferences to produce and consume a product, with a price reflecting economy-environment harmful interactions. Figure 2.3 illustrates this argument.

Other indirect tools, although less common, may be applied to change stakeholders' preferences, *e.g.* legal environmental regulations, quotas on pollution.

While this holds true in theory, it encounters difficulties in practice. Where economic and legislative tools to internalize externalities are numerous, methods to assess environmental damages are still at an early development stage. Indeed, quantifying environmental mechanisms may require a significant amount of time and expertise and often implies value choices, which may seriously impede the results validity and reliability.

Yet, some techniques, notably *Industrial Ecology*'s tools, proved to be effective in assessing environmental impacts. In parallel, economic valuation methods for environmental degradation – *i.e.* described in the EU's ExternE projects series – are already used as informative support in some European and national policies, *e.g.* Eco-taxes, Carbon taxes, pollution trading permits prices, etc. [Bickel and Friedrich(2005)] Although, up to today, only few policies are actively based on such estimates.

This next section informs the reader on how *LCA* and *IO-EA* are used to quantify environmental impacts.

2.2 Ecological Economics and Industrial Ecology

Interdisciplinary by nature, *Industrial Ecology* is a recent field which emerged from the need of developing industrial solutions adopting a symbiotic behaviour towards their receiving environment, *i. e.* the biosphere. *Industrial Ecology* seeks at designing industrial systems inspired from efficient natural processes. It implies developing industrial applications that satisfy the sustainable framework conditions defined above, without compromising its long term viability.

Thus, mature type-III industrial systems share common characteristics with processes found in the biosphere:

- they optimise their use of resources,
- they evolve through stages of growth,
- they respond to external stimuli and environmental constraints,
- they emit heat and material residuals, which are not considered as waste,

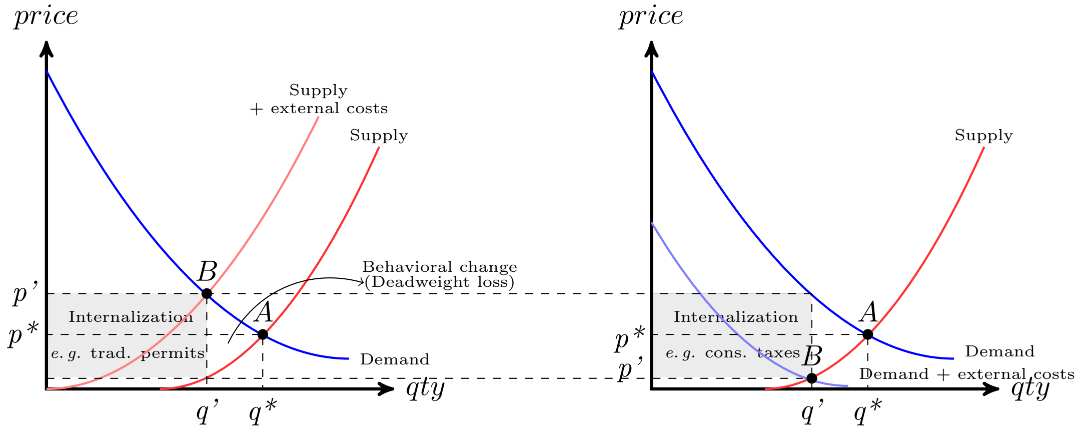

Figure 2.3: Representation of externalities in a supply-demand diagram, on a competitive market. Intersection ***A*** is the original market configuration with price $p*$ for a quantity $q*$. When integrating external costs on the producer (left graph) or on the consumer (right graph) curve, the market switches to another optimal configuration ***B***. The deadweight loss triangle: consumers and producers' preferences change as new costs are considered. In both cases, the market output ***B*** is similar. The revenue from taxes or trading permits is represented by the shaded area. This additional cost is borne by the entity that has the greater inelasticity to the price change. *Source: completed by the author.*

- the notion of waste becomes inexistent as symbiotic exchanges always occur,
- these systems are closed and self-sustaining,
- closed systems imply the reversibility of processes, without minimal loss of material and quality over time. This is however not possible due to entropy increase.

It is believed that, in order to obtain such mature industrial system, some fundamentals have to be considered:

- industrial processes are nested within the economic sphere, which is itself part of a finite closed natural system,
- laws of mass and energy conservation and entropy apply: "there is no such thing as a free lunch",
- inter-systems interactions, *e. g.* economic, social and environmental harmful impacts related to the product *life cycle*,
- interconnectedness between the economic, social and environmental dimensions. Any decision from an industrial entity will operate a welfare move in every of these aspects. The aim to get as close as possible to a net Pareto optimum should be

prioritised in any decision-making process.

Therefore, *Industrial Ecology* principles are a practical answer to *Ecological Economics*'s needs to quantify economy-environment interactions omitted by markets mechanisms, through the consideration of products' life cycles. *Industrial Ecology* offers methods to analyse a product life cycle. This study chooses to focus on *LCA* and *IO-EA*.

2.2.1 Product life cycle

Goods are considered in relation to the successive industrial steps that bring life and added-value to the product, till the end of its existence. It is a philosophical approach promoted by the European Commission's IPP *green paper* [Commission(2001)]. It particularly emphasises on EPR[1].

More specifically, it designates the cyclical pattern of a product *materialisation–dematerialisation.*

Such extent of analysis usually refers to a *Cradle-to-Grave* scope. *Cradle-to-Gate* focus is also encountered – it ranges from the conceptual phase of a product but stops at its manufacture at the factory plant. This perspective is usually used for the production of business-to-business EPD[2]. The figure 2.4 illustrates a Cradle-To-Grave product life cycle.

2.2.2 Impact assessment

2.2.2.1 Life Cycle Assessment

The first tool for analysing products' life cycles this study covers is LCA. This tool illustrates economy-environment interactions related to a product system by compiling elementary flows, evaluating the resulting *potential* environmental harm and interpreting the outputs to draw conclusions on the product soundness.

A strong point with LCA is to directly visualise the environmental performances of the product life cycle when changing parameters in the model – *e.g.*, product Eco-Design. It prevents from optimising separately each of the product life cycle phase and shift the environmental burden elsewhere within the value chain. ISO 14040-44 norms series may be used as guidelines to ensure transparency and validity.

Previous works have proven the suitability of LCA for environmental damages economic valuation, as seen in the Nuclear Energy Agency[Agency(2001)] studies, among others.

Yet, LCA has also been the object of criticism in regards to the variability in the end-results due to value choices, allocation methods and system boundaries definitions. Indeed, assumptions

[1] Extended Producer Responsibility. For a definition, see the Glossary at page xii.
[2] Environment Product Declarations. For a definition, see the Glossary at page xii.

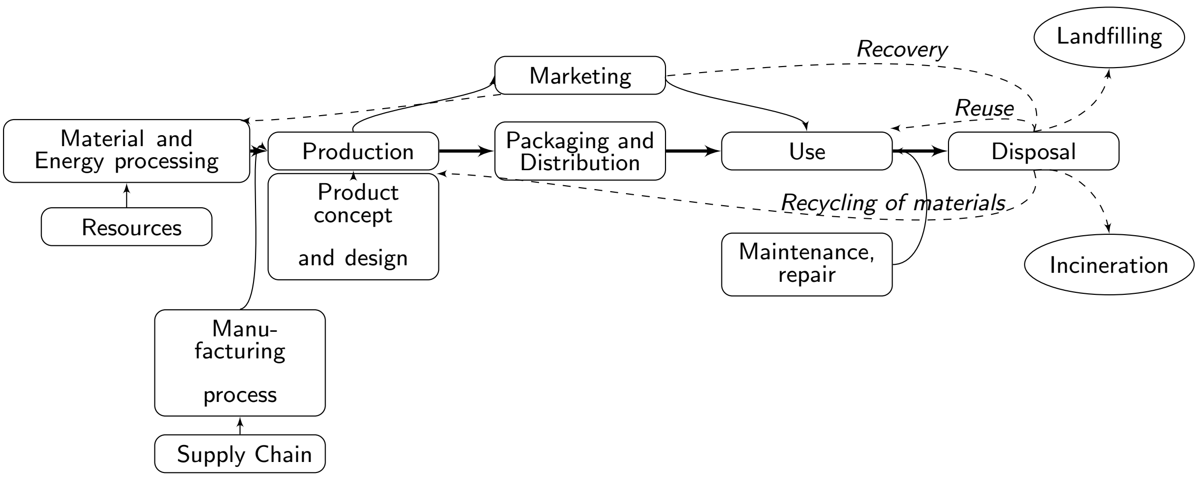

Figure 2.4: Cradle-to-Grave life cycle stages. *Source: European Commission. Green paper on integrated product policy. 2001; completed by the author.*

and value choices made during the analysis may importantly affect the model outputs. Thus, it is thought that part of environmental impacts may possibly be omitted if inappropriate system boundaries or methods or specific choices are made.

2.2.2.2 Input-Output analysis with Environmental Accounts

The input-output analysis is an economic model using national input-output statistics tables: they are matrices representing inter- and intra-sectorial economic outputs required as inputs for the marginal production of one specific sector. The flows are expressed in monetary units. To go beyond economics, recent versions of input-output tables have been featured with their equivalent environmental accounts, associating monetary flows with their physical counterparts. This improvement allows input-output tables to not only be used for national accounting purposes, but also for environmental impact assessment. It refers to IO-EA.

However, IO-EA, as with LCA, presents disadvantages.
Statistics fed in the tables are usually highly aggregated, fitting more to industrial sector-scale rather than process-level analysis.
Second, several important assumptions damper its validity: fixed scale and technical coefficients prevent the model from considering economies of scale or technical progress and productivity gain through time and quantities. The model is bound to be linear.
Third, technological abilities, natural resources stocks and productivity are assumed to be roughly the same all over

the world. It discards international trade theories and different productivity ratios. Also, the demand is exogenously determined, and sectors are characterised by the production of one output only.
Finally, these matrices contains a large amount of data which makes it difficult to be maintained regularly. Most of IO-EA tables are now more than a decade old.

On the other hand, IO-EA is believed to be a powerful tool. While it remains less accurate than LCA, it encompasses a much broader scope as the boundaries are the country in which it is applied itself. Moreover, IO-EA has the ability of considering round-by-round effects[1].
Finally, the Danish statistics database, maintained by Denmark Statistics, has been adapted in a LCA software format.

The application of these two tools in a collaborative manner is believed to yield more benefits than if used separately. Indeed, the accuracy and the consideration of uncertainties and sensitivity in the end-results of a LCA is completed by the broadness and robustness of results delivered by an IO-EA. Such combination delivers solid results that can further be used for an economic valuation of environmental impacts.

2.3 Economic valuation of environmental degradation

Economic valuation of environmental degradation from harmful mechanisms – *e.g.* the release of air pollutants, greenhouse gases and micro-particles – has become a real concern for the European Commission. Methods for monetizing environmental degradation may become a powerful tool in decision and policy-making. 20 years ago, the first projects attempting to model costs endorsed by power generation through the combustion of fossil-fuels were already on the way [ExternE(1995)].

The first noticeable efforts regarding global warming cost estimates were probably in 1996, with the IPCC work for GHG estimates for the periods 1991-2000 and 2001-2010. In parallel, a series of EU's co-financed projects (ExternE and sub-projects NewExt, ExternE-Pol and FUND) started to issue new publications of cost estimates from GHG releases, air pollutant and biodiversity loss, related to industrial processes, *e.g.* power generation and transport.

However, cost estimates use proved to be delicate. Indeed, estimates techniques, propagation of uncertainties – in regards to valuing what is not valuable or to integrating and pondering

[1] It corresponds to the additional production of intermediaries *i'* inherently enhanced by the marginal production of intermediaries *i* that serve the purpose of producing the final output *j*.

the expected values of rare but important environmental casualties – are factors among others that render sensitive results. [Schwermer(2007)] proposes a framework through the German Federal Environment Agency's *Methodological Convention* to work around some of these difficulties.

Another difficulty often associated to this field is the extreme sensitivity of final estimates in respect to specific parameters, *e.g.* the social rate of discount, the assessment of risk aversion, the pure time preference or the inclusion of Damocles or Pythias-type risks. These parameters are very characteristic of people and society preferences regarding the future and the natural capital. Moreover, some cost categories cannot be assessed on revealed preferences[1], but stated preferences[2], through surveys to "reveal" the WTP[3]. These parameters have a strong influence on the final results, and makes existing studies hardly comparable. However, it is possible to reach a consensus and use recent findings to establish lower, central and higher estimates for uncertainty assessment purposes [Enquete-Kommission(1994)].

Thanks to resources allocated to related projects – *e.g.* EU's ExternE projects series, including New-Ext, FUND and others –, the research effort in this domain has resulted in significant progress in 20 years. Some recognition has been shown in that regard. It is specially the case in policy-making where benefits transfers were meant for compensation services design, *e.g.* UK's Government Economic Service measures notably [Enquete-Kommission(1994)].

[1]Evaluation of individuals preferences according to their behaviours towards a market good in connection to a non-market good. Usually the preferred and simplest way of assessing non-market goods. Several costing tools exist: direct (market prices, replacement costs) or indirect ones (hedonic pricing, travel cost).

[2]Relies upon interviews and survey to determine individuals preferences. However, high risks of bias and subjectivity can be expected from such methods.

[3]Willingness-To-Pay. For a definition, see the Glossary at page xii.

3

The case of nonwoven fabric in Denmark - Methodology

3.1 Aim of the analysis

This chapter assesses and monetizes damage – within a 100 years time horizon – inflicted by the manufacture of nonwoven fabric in 2011 upon vital ecosystem services that support human life, maintain agricultural productivity and ensure sustainability of processes in the biosphere. Because economic valuation of environmental damage is still at an early stage of development, this study focuses solely on impact categories thoroughly covered by the literature: Climate change and Environmental impacts (human life impairment, agricultural damage and material loss). Other impacts – *e.g.* accidents and energy security – although very important, lack of scientific foundations.

A Cradle-To-Gate analysis of the nonwoven fabric product system is conducted through both LCA and IO-EA.

The case of nonwoven fabric matches well with the arguments presented in this work. The nonwoven fabric requires significant amounts of hydrocarbons-based thermoplast polymers, *i.e.* polypropylene, and energy, *i.e.* fossil-fuels. It is representative of the widespread use of hydrocarbons compounds in industrial applications. Analysing its Cradle-To-Gate value chain reveals harmful environmental mechanisms that can be economically valued.

This analysis and its reporting tries to comply with the standardised structure suggested by the German Federal Environment Agency[Schwermer(2007)]. This structure is depicted in Appendix A.

On the other side, the LCA study is used to derive the *Cumulative Energy Demand* of the functional unit, which translates in to GJ of primary energy used along the Cradle-To-Gate scope of the product system, in order to apply Denmark ”green” and energy tax rates. This allows to confront environmental damage estimates with the current Danish taxation system to highlight potentials and barriers in covering/compensating for environmental degradation. The idea is illustrated in Figure 3.1.

3.2 The life cycle models parameters and methods

3.2.1 What is polypropylene nonwoven fabric?

The polypropylene nonwoven fabric is a synthetic material and refers to fine sheets of fibres bonded together. Porous, thin and light weight, this fabric is made directly from individual fibres. Because it is not made by weaving or knitting, it is not required to convert the fibres to yarn or other additional knitting operations, giving it a specific structure robustness. Generally, they consume a high percentage of hydrocarbons-based polymers, *i.e.* polypropylene. Its elemental composition and processing determine its physical properties. The dominance of polypropylene makes the fabric easily recyclable.[Sacchi(2012)]

This product is mostly made of polypropylene granules, colorant and/or softening additives and other hydrophilic agents, with a product grammage ranging from 8 to 15 g/m^2. This fabric is mostly the result of a *spunbond*, *meltblown* or *spunbond/meltblown/spunbond* (SMS) process, where the polypropylene material is extruded, melted, dyed, stretched and dried.
The uniform distribution of the fine filaments of *spunbond* and *meltblown* makes the product suitable for hygiene, automotive and other industrial applications.

3.2.2 The functional unit

The functional unit satisfies the equivalent of 1 t of white nonwoven fabric. The reference flow to achieve the functional unit is 1 t of white nonwoven fabric. The choice of a mass unit, ton (t), discards density and volume aspects. It also remains significant in respect to the total production volume in Denmark. White nonwoven fabric is the most widespread coloured nonwoven type on the European market (80%).

3.2.3 Scope of analysis

LCA and IO-EA are used to analyse the nonwoven fabric life cycle. The life cycle scope of analysis is Cradle-To-Gate for the year 2011, in Denmark. It encompasses the early stages of the product materialisation, *i.e.* energy capture and transformation, raw materials excavation, down to packaging operations and other necessary in-house processes at the factory.
This choice is relevant for several reasons:

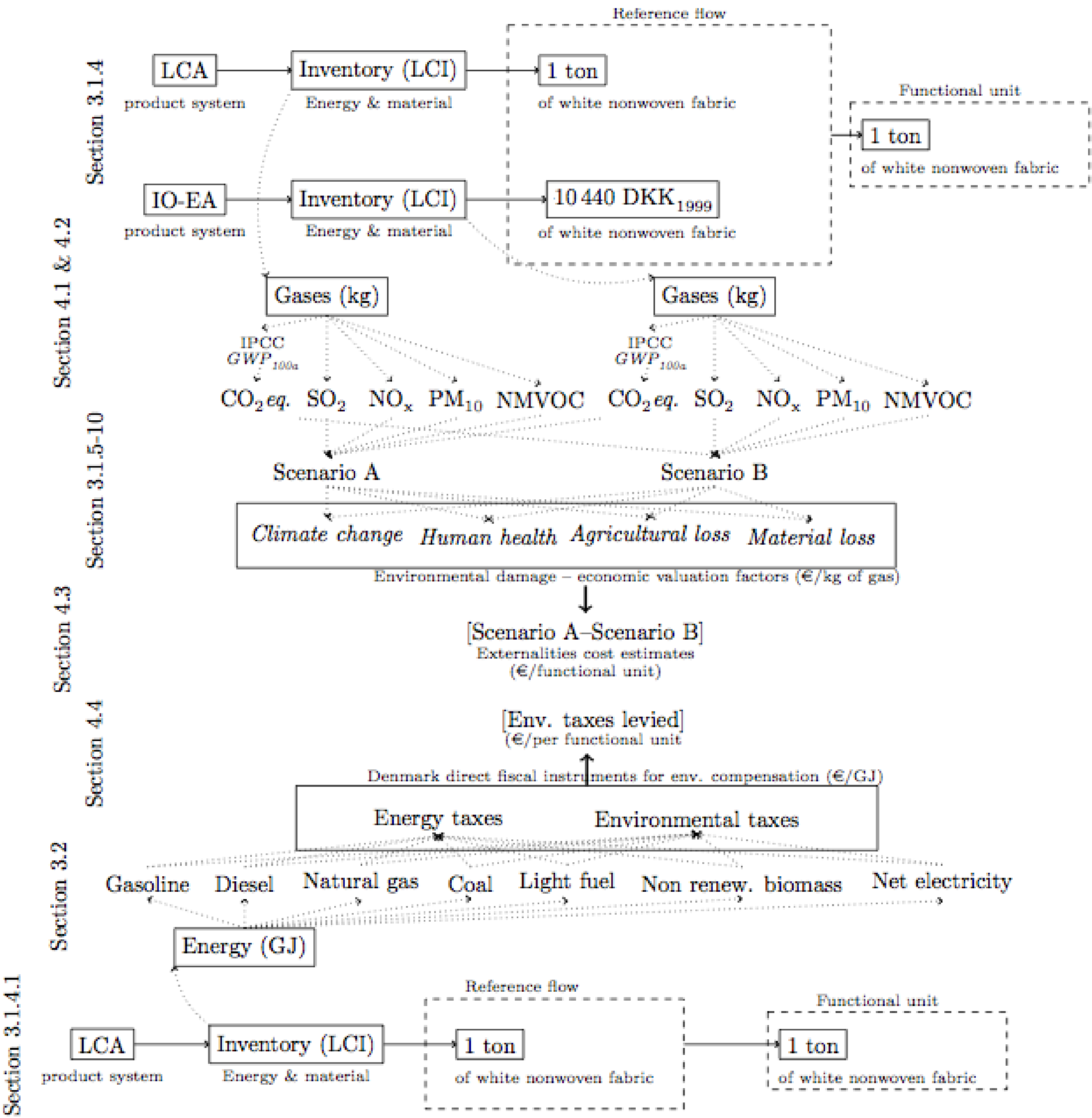

Figure 3.1: Methodology followed for obtaining externalities cost estimates and assessing the Denmark environmental taxes cover. *Source: completed by the author.*

- it facilitates a further use of these results by other life cycle analysts, to further extend the scope down in the Supply Chain,

- it is the most comprehensive scope allowed before the analysis suffers from invalid and inaccurate data,

- it allows to visualise the environmental burden borne by the product once it reaches the market.

Figure 3.2 illustrates the nonwoven fabric product system used.

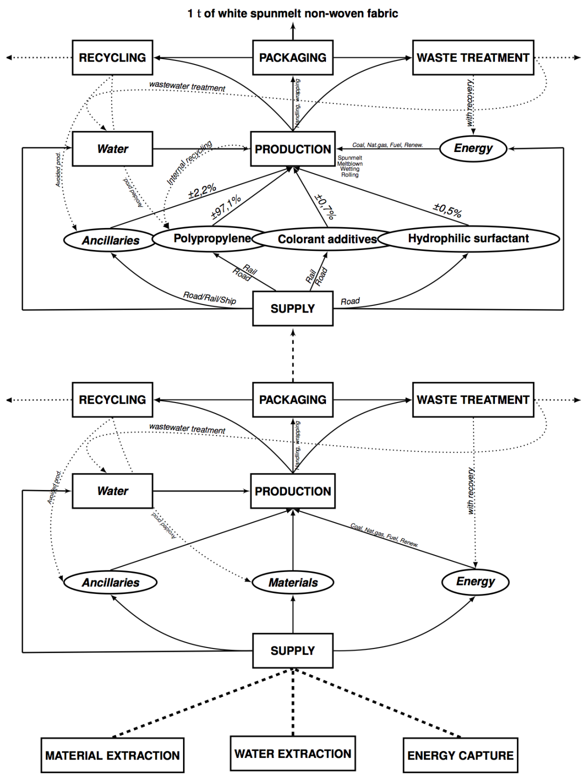

Figure 3.2: Simplified representation of the white nonwoven Cradle-To-Gate product system. *Source: Sacchi, 2012.*

3.2.4 Life Cycle Inventory

3.2.4.1 LCA inventory

The LCI database provided by [Sacchi(2012)] offers a comprehensive Cradle-To-Gate product system. It is available as a digital format in Appendix F. It includes materials extraction, energy capture and transformation, waste treatments and energy recovery systems specific to Denmark technologies and infrastructures. The functional unit, scope of analysis and model parameters fit with the present study.

This LCI covers the production of 43,5 kt of white nonwoven fabric. The national production being of 72 kt in 2011 [Denmark(2011)], it is sufficiently representative.
The product system encompasses 2 025 processes and derives statistical variance, mean and distribution patterns throughout a decade for most of the elementary flows – to assess uncertainty propagation. The model presents satisfying performances in reliability and validity, tested through sensitivity, quality and uncertainty checks. Additionally, most of primary data are issued from 2011 sources.

Finally, its reporting form and the methodology applied follow international standard norms. They have been certified compliant to the ISO 14040:44 norms series. Figure 3.3 illustrates the Inventory analysis given by this LCA model.

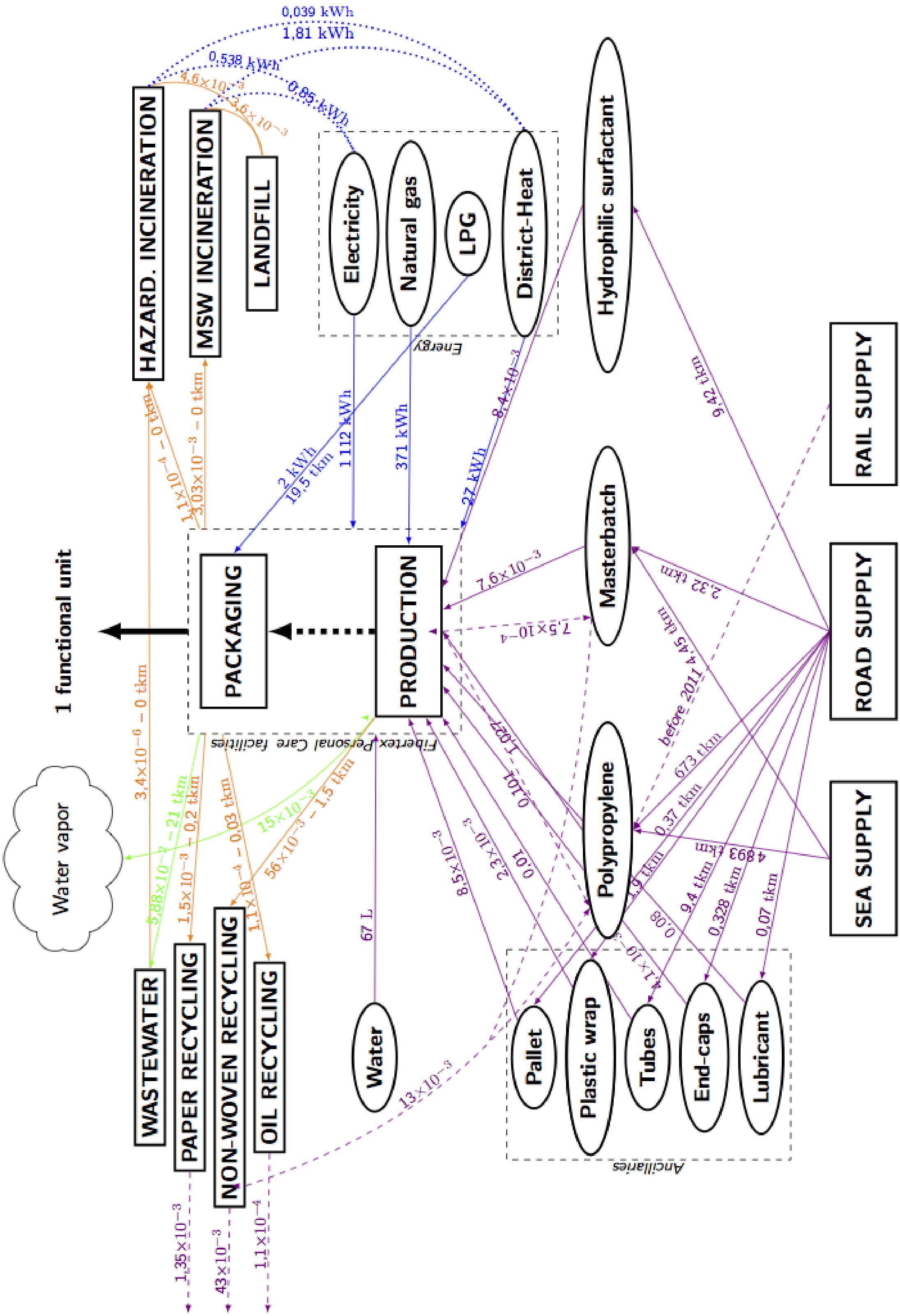

Figure 3.3: Process tree - LCA Inventory analysis of the product system. Legend: Material flows are violet. Energy flows are blue. Solid waste flows are orange. Wastewater flows are green. Dashed flows are recovered materials. Dotted flows are recovered energy. tkm = ton kilometre, kWh = kilowatt-hour, L = litre, figures without units = functional unit mass ratio. *Source: Sacchi, 2012*

A summary of the model parameters as well as the LCI results are described in Appendix B.

3.2.4.2 IO-EA inventory

The LCI used for the IO-EA analysis is provided by Denmark Statistics' 2003 supply-use tables, which contain input-output statistics over the 1995-1999 period. In collaboration with other interested third parties, *i.e.* 2.-0 LCA Consultants, the national input-output inverted matrix has been associated with Environmental Accounts and formatted to be used with an LCA software – Pré's SimaPro, in this case.

A Cradle-To-Gate product system for nonwoven manufacture in Denmark is available. The process, created in 2003, has been updated in 2005 by Bo Weidema and 2.-0 LCA Consultants. It contains 305 processes: the manufacture, coating, laminating and distribution of nonwoven and related materials, as well as capital equipment-related needs.
Paradoxically, while IO-EA is appreciated for having broader system boundaries than LCA, this product system contains only 305 processes – against 2025 for the LCA model. Yet IO-EA, unlike LCA, integrates multi-loop effects: some industries are referring to themselves or to other industries which refer back to them. Hence, where the product system shows 305 processes, many more remain not visible. This LCI presents satisfying valid and reliable data as it has been reviewed by an external expert, Niels Frees, from the *Danish LCA Centre*.

Flows within this LCI are expressed in *Danish kroner*, on a 1999 price index basis. Considering prices rate change in the country this last decade, the output value of 1 t of white polypropylene-made nonwoven fabric in Scandinavia was set at 10 440 DKK_{1999} (1 403€) [Denmark(2011), Risi(2012)].

Yet, because of industrial secrecy, the margin-free output price of 10 440 DKK_{1999} for 1 t of nonwoven in 1999 cannot be verified. A description of the model parameters as well as the inventory results are described in Appendix C.

3.2.5 Environmental impact assessment methods

The following impact assessment methods are used:

- Climate change: the 2007 IPCC's GWP_{100a} characterisation model is used to assess the marginal radiative forcing effect of GHG and express them in a common unit, kg of CO_2 *eq.*,
- Human life impairment, Agricultural and Material losses: no characterisation model is used here.

[1] Particle matters $\leq 10\mu m$
[2] Non-Methane Organic Volatile Compounds

> However, LCI streams of SO_2, NO_x, PM_{10}[1] and NMVOC[2] are collected and expressed in mass, through the EcoInvent 2.0's methods *Selected LCI results* and *Selected LCI results, additional.*

Hence, only the IPCC GWP_{100a} characterisation model is used for characterising GHG-related emissions while other gas streams are simply collected without characterisation factors transformation. No classification, normalisation or weighting operations are performed, in order to avoid any value-choices implication. Economic valuation methods are applied to these figures.

3.3 Economic valuation methods

For each of the four environmental mechanisms studied, an economic valuation method is proposed.
These methods are the result of complex studies, considering individual and societal preferences, social discount rates, in/exclusion of Damocles[3] and/or Pythias-type[4] risks, etc.

A *bottom-up* approach, so called *impact pathway* method, is used to track the environmental mechanisms source down to the endpoint receptors to highlight a cause-effect relation, through dose-response functions. It allows, providing enough information and data are available, to derive *marginal costs* of pollution. It has been applied in several EU's research projects. The method identifies the sources of pollution, considering dispersion, atmospheric transportation and chemical transformations, and assesses their effects on endpoint receptors in relation to the marginal production of a good. These considerations are computed by the WindRose Trajectory model[5], for ExternE studies.

Ideally, the valuation is based on damages inflicted on end-receptors – *e.g.* climate refugees – or the risk of damages – *e.g.* increase of flood risk – and not from the pollution source – *e.g.* GHG release. When possible, these methods try to value direct damage costs in relation to their market prices or individual preferences – *i.e.* through WTP.
Yet, because of uncertainties nested in preferences, catastrophic events and risk

[3]Large catastrophic events with low frequency of occurrence. For a definition, see the Glossary at page xii.

[4]Events with uncertain damage extent and uncertain frequency of occurrence. For a definition, see the Glossary at page xii.

[5]A model used by the ExternE's software EcoSense, originally developed by the Harwell Laboratory, to estimate particles dispersion on a regional scale

[1]Economic human behaviour when exposed to uncertainty of risk occurrence. For a definition, see the Glossary at page xii.

[2]Marginal costs of pollution reduction measures. For a definition, see the Glossary at page xii.

aversion[1], it is sometimes preferable to refer to avoidance costs (or abatement costs[2]) expressed by societal, political and/or experts preferences – *e.g.* $CO_2 eq.$ 450 ppm limit, Kyoto negotiations – to evaluate costs of adjustment to reduce environmental consequences. However, such measure is only viable if the environmental "yardstick" is generally accepted by the society.

3.3.1 Average value transfer

Because the resources allocated to this work would not allow empirical analyses of economic valuation from environmental degradation specific to this context, existing European estimates are used instead. Applying these estimates in a context other than the policy-context they originally stemmed from present the advantage of being time and resources saving. Nevertheless, because these estimates are sites-specific, it is necessary to transfer the central tendency of these figures to make them fit this case study – *average value transfer*. However, for these transfers to remain valid, it must be assumed that individuals' preferences in socio-economic terms, which may influence their revealed or stated preferences *e.g.* well-being, traditions, income, education level, are similar to the individuals' preferences considered in this study. The entirety of estimates used are European derived. Hence, it is reasonable to assume a certain similarity between Danes' preferences and preferences expressed by the average European citizen.

3.3.2 Spatial scope

The environmental damages on end-receptors are associated to the release of GHG and air pollutants. While some of it originates a direct source – *e.g.* release of air pollutants during the transport of materials – another part originates indirect sources –*e.g.* GHG release during the treatment of wastewater, incineration of municipal solid waste. Both direct and indirect sources are considered. The consequences of releasing GHG is based on economic and productivity losses due to climate change. To the same extent, the consequences of air pollutants release is based on costs of diseases and hospitalisation, damage to buildings materials and crop losses in agriculture and forestry.

3.3.3 Climate change

To assess economic consequences from GHG releases, the estimate from [Downing(2005)], based on the FUND project figures, is chosen. It gives a marginal cost for GHG release of 68€/t of $CO_2 eq.$. This figure is the central estimate of a review encompassing 104 peer-reviewed studies. These studies all consider a 100 years time horizon, environmental consequences on a world scale, a

[1]Pure Rate Time of Preference - Discounting rate individuals apply to future consumption, with an unchanged consumption per capita over time. The magical utility of consumption (μ) and the rate

PRTP[1] of 1% and include equity weighting[2]. This model has been approved among European scientists. However, [Downing(2005)] considers this figure as a "best-guess" value only, since great uncertainty makes the results widely varying.

Hence, an upper bound estimate of 284€/t of $CO_2\,eq.$ – provided by the same model with a SRTP of 0% – is used for sensitivity purposes.

On the other side, a lower bound of 19€/t of $CO_2\,eq.$, provided by the EU's project NewExt, is used. Unlike previous estimates, this calculation does not assess direct damage costs but avoidance costs: it represents abatement costs to reach 2012 Kyoto treaty's GHG emission levels – reducing 1990's GHG emissions of 8% by 2012. Each additional ton of $CO_2\,eq.$ released makes it more difficult and engages more resources to comply with the Kyoto negotiation terms. The model assumes that trading CO_2 permits is allowed internationally. Still, one may criticise the short-term characteristic of this estimate. Yet, it is believed to be a prudent lower bound estimate.

3.3.4 Human life impairment

The assessment of human health degradation relies too upon the *impact pathway* method and consists into two main calculation steps:

1. the direct and indirect dose-response relationship between the pollution emission and the degradation observed,

2. and the valuation of the degradation based on individuals preferences.

Air pollutants, thanks to dispersion models, are correlated to human heath degradation, under the form of diseases, inabilities, death risk and other concerns. A *per ton of air pollutant* average is derived and

of capital growth over time (g) can be summed with the PRTP, which equals SRTP (Social Rate of Time Preference, with SRTP = PRTP + $g \times \mu$). Mechanically, when the PRTP or g or μ increases, SRTP increases too. The SRTP is used to discount future environmental damages lasting in time (5, 10, 20, 100 years). The common practice is to set a SRTP at 3% for damages lasting 20 years or less (PRTP=1,5%, μ=1% and g=1,5%), and 1,5% for intergenerational damages, that is more than 20 years (PRTP=0%, μ=1% and g=1,5%), and 0%, for sensitivity purpose (PRTP=1,5%, μ=1% and g=0%). The idea is that present generations importantly discount environmental damages in a near future, but costs are not discounted for future generations, supporting the idea of sustainability of actions between generations.

[2] Refers to a higher weighting of damage costs for the less developed countries. Poorer countries are structurally composed of activities relying on climatic conditions. Additionally, more developed countries have had abundant resources to set up Climate change adaptation plans.

[1] Value of Life Year Lost - it is a measurement unit used to assess the marginal effect of toxic compounds in terms of average lifetime they withdraw from an individual life span, considering acute and chronic impacts.

expressed in VLYL[1]. The VLYL is nothing but the aggregation of damages on a person life span.

Table 3.1, based on the [Bickel and Friedrich(2005)] figures, summarises the average values used in this study, per 1 t of air pollutant released in Europe (EU-25).

- The environmental mechanism underlined by the release of SO_2 and NO_x is the indirect formation of *sulphate* and *nitrate aerosols* in reaction with ammonia in the air and the indirect formation of *ozone* by association of NO_x with VOC[2].
- The endpoint impacts considered for *sulphate aerosols* are: the development of cardio-pulmonary morbidity, *e.g.* hospitalisation, consultation of doctor, asthma, sick leave and the restricted activity.
- The endpoint impacts considered for *nitrates aerosols* and indirect formation of tropospheric *ozone* are: the increase in mortality risk and morbidity, *e.g.* respiratory hospital admissions, days of restricted activity, asthma attacks, symptom days.
- For the PM_{10}, the deposition on organic tissues and respiratory systems is considered. It increases the development of cardio-pulmonary morbidity, *e.g.* cerebrovascular hospital admissions, congestive heart failure, chronic bronchitis, chronic cough in children, lower respiratory symptoms, cough in asthmatics.
- As for NMVOC, they lead to a tropospheric ozone formation, enhancing the risk of asthma and other respiratory diseases.

Economic valuation of these degradation types remain the most delicate to assess, as they are costly but also empirically and ethically challenging to estimate. Their estimates rely upon three types of cost [Schwermer(2007)]:

- diseases cost: expenses borne by the health system, *e.g.* hospitalisation, medicines,... Yet, when covered by a personal insurance, as mentioned by [Schwermer(2007)], they do not constitute an externality,
- opportunity cost: impairment of life quality brings loss in productivity and increases absenteeism at work,
- individual disutility: because of physical disability and heavy illness, the individual's utility is reduced by his inability to perform leisure activities,... This last type of cost cannot be measured by market prices, but is reached through surveys about individual's WTP to

[2] Volatile Organic Compounds

avoid the occurrence of the problem.

The release of toxic particles not only increases the risk of diseases development but also impacts the marginal risk of death, called VSL[1]. Several methods include the cost of increase of death risk in the valuation model. It is possible to reach such values by consulting EU countries VSL estimates in traffic accidents cost analyses: the European Commission's Environment Directorate-General recommends a value of 1,4 M€ per person, the estimate is between 0,6 and 3,9 M€ for the United Kingdom, while the German estimate is about 1,2 M€. It can also be estimated by survey, based on individuals' preferences: the 2004 NewExt study reveals an average WTP to prevent death among European individuals of about 1 M€. This figure is used to assess the marginal mortality impact of air pollutants in this study.

Pollutant	Morbidity	Mortality	Sum
SO_2	1 040 €	2 020 €	3 060 €
NO_x	1 000 €	2 120 €	3 120 €
PM_{10}	4 000 €	8 000 €	12 000 €
NMVOC	170 €	60 €	3 060 €

Table 3.1: Damages costs for human health impairment in €/t of air pollutants released. *ExternE, EcoSenseLe, 2006*

[1]Value of Statistical Life

3.3.5 Agricultural loss

The valuation of economic loss due to reduced crops productivity is relatively easier, since it is entirely based on damages costs, given by market prices. Dose-response functions have long been established and improved along the ExternE studies, relating molar concentration of pollutants (SO_2, NO_x …) with the reduced crop productivity per hectare or m^2.

The table 3.2 shows the figures given by EcoSenseLe [ExternE(2006)], which are used in this study. The damages related to SO_2 are assessed through the direct deposition of SO_2 on crops and by the indirect dry precipitation of sulphur and sulphuric acid. For NO_x, the damages are based on the deposition of nitrogen and on the action of ozone on the crops. As for the NMVOC, the indirect effect of ozone formation in the troposphere is assessed.

Pollutant	Crops productivity loss
SO_2	−10 €
NO_x	130 €
NMVOC	640 €

Table 3.2: Damages costs for crops productivity loss in €/t of air pollutants released. *ExternE, EcoSenseLe, 2006*

With an initial atmospheric concentration of SO_2 less than 15 $\mu g/m^3$, the marginal effect of SO_2 is positive, increasing the average fertility on the yield of crops.

3.3.6 Material losses

The natural weathering of materials over time is enhanced by a 10 to 100 factor with the presence of air pollutants such as SO_2 – *e.g.* corrosion by acid rain – or ozone – *e.g.* degradation of organic tissues.

Accurate dose-response functions relating pollutants concentration with abnormal corrosion is provided by the UN-ECE International Cooperative programs, conducted in different countries.

Table 3.3 shows the figures given by EcoSenseLe [ExternE(2006)], which are used in this study. The damages related to SO_2 are assessed through the dry precipitation of sulphur and sulphuric acid. For NO_x, the damages are based on the action of ozone on organic materials and tissues.
The reader must know that costs related to the degradation of culturally symbolic monuments and other buildings of cultural significance are not included in these figures.

Pollutant	Material losses
SO_2	230 €
NO_x	70 €

Table 3.3: Damages costs for material losses in €/t of air pollutants released. *ExternE, EcoSenseLe, 2006*

3.4 Economic integration of environmental externalities

Externalities estimates are then confronted with the current environmental and energy taxes package applied in Denmark in order to assess the actual integration of externalities.

The next sub-section describes the development of direct[1] "green" taxes. They are designed to limit the proliferation of energy-intensive products and their consequent release of GHG and air pollutants. These tax rates are used to estimate taxes levied for one functional unit.

3.4.1 Current Denmark tax structure

There is, since 1995, a strong will in designing efficient environmental policies through the development of "green" regulatory taxes[2] along with taxes on energy use. However, a distinction needs to be made: while energy taxes intend to reduce the use of non-renewable sources of energy and energy-intensive products, the "green" taxes aim at reducing the release of GHG, air pollutants, CFCs, and other harmful waste, resulting from industrial applications – including the use and combustion of hydrocarbons. Even if energy

[1] Levied directly from the taxable stakeholder. To be distinguished from an indirect tax, which is levied by an intermediary from the stakeholder paying the tax, *e.g.* VAT.

[2] A regulatory tax aims at reducing the consumption of a service or good. To be distinguished from a fiscal tax, which only aims at levying funds.

taxes reduce the release of GHG and air pollutants – through taxation of fossil-fuels use – they are not regarded as environmental taxes. Yet, because of their indirect regulatory effect on gas emissions, they are considered in this analysis.

A change in environmental regulatory taxes design has been observed the last decade: while it was originally targeting households energy and intensive-energy products consumption, the tax burden gradually shifted to the industry sector, to limit regressive and undesirable distributional effects on low-income households.[Wiera(2005)]
Not only was it meant to respect the national GHG emissions reduction targets and fulfil the Kyoto agreement commitments, but it has become today a non-negligible source of public income – ±1,3 billion €$_{2011}$ in 2011 [SkatteMinisteriet(2011)] – recycled in labor tax burden reduction and subsidies for "green" applications investments – while preventing the taxes from penalising the international competitiveness of these companies. Several Danish Ministry of Taxes statistical reports confirm the success of these reforms, which achieved the following objectives[SkatteMinisteriet(2010)]:

- it encouraged the manufacture of less environmentally impacting products,
- it gave a competitive advantage to greener businesses,
- it promoted energy-saving practices,
- it encouraged the development of GHG-free energy sources through subsidies,
- and it facilitated/preserved employment through labor tax burden reduction.

The last energy taxes package, the Spring package 2.0, came into force in 2010. It observes different taxation rates on gases emissions (t of CO_2, SO_2 and NO_x) and energy use (GJ) according to the magnitude of fossil-fuels use – heavy, normal and light energy intensive processes – but also on the type of activity – energy production, manufacturing processes, heating and transport. It is worth noticing that the primary agricultural, metallurgical and mineral sectors are not covered by these reforms, not to damper too importantly their international competitiveness. The environmental taxes structure and rates of the Spring package 2.0 is shown in the Appendix E.

3.4.2 Compensation for externalities in the nonwoven fabric value chain

The environmental cost estimates are confronted with the income levied from "green" and energy tax rates – expressed here in €/GJ – currently applied in Denmark.

However, this analysis has some limitations:

- Ideally, an average between the LCA and IO-EA energy inventoried values should be used to be compared with the environmental cost estimates. Yet, it is not technically possible to obtain energy quantity streams from the IO-EA inventory. Thus, only the LCA energy inventoried values are used. They are multiplied by the "green" and energy tax rates contained in the current Spring package 2.0.

- Figures related to heating are very low since the LCA model assumes that most of the heating is provided through a district-heating network originating a MWI[1] plant. Hence, the indirect environmental burden associated to heating is instead allocated to the waste incineration process, fully accounted in the LCA model – but in the industrial processes section.

- the Spring package 2.0 tax reform does not entail MP_{10} and NMVOC emissions. It implies a partial inability of the Danish taxation structure to cover for Human health degradation and Agricultural loss-related externalities.

- Finally, processes related to logistics operations, although distinguished in the LCA model, are evidently not specified in the taxation structure: the tax rates associated to industrial processes are used instead.

The environmental damage economic estimates and the environmental Danish taxation system are depicted in the next chapter.

[1] Municipal Waste Incineration plant

4

The case of nonwoven fabric in Denmark - Results

4.1 Cradle-To-Gate LCA results interpretation

The Cradle-To-Gate LCA model outcomes are presented in the table 4.1. The figures represent the "best guess" values obtained through a 10 000 runs uncertainty test.

Pollutant	Unit	Manuf.	Elec.	Transpt	Logist.	Heat	Total
GHG[a]	kg of CO_2 *eq.*	1 879,9	638,02	114,24	21,21	6,24	2 659,65
SO_2	kg	3,52	1,02	0,62	0,04	0,019	5,22
NO_x	kg	2,98	0,76	0,99	0,06	0,017	4,8
PM_{10}	g	250	16	28	3	$5{,}9\times10^{-4}$	297
NMVOC	kg	3,37	0,11	0,05	0,04	3×10^{-3}	3,57

Table 4.1: Life Cycle Impact Assessment results for one functional unit. *Source: completed by the author.*

[a]from the 2007 IPCC GWP_{100a} characterisation model.

A detailed listing shows that most of CO_2, SO_2, NO_x, PM_{10} and NMVOC originate the processing of the embodied energy of polypropylene and the electricity production. The electricity production – the electricity use in the last assembly processes in Denmark – dampers heavily the environmental performances because of the reliance on fossil-fuels: 70% from fossil-fuels (mainly hard coal), with a remarkable but not sufficient 30% from CO_2-free energy sources (wind and biomass, with 20% and 10% respectively). Besides road and shipping supply, the processing of hydrocarbon polypropylene granules and hydrocarbon-issued electricity widely condition the product system environmental performances. Gas and particles emissions behind the production of heat is particularly low due to allocation methods, associating the environmental burden with waste incineration and slag landfilling, and not with the co-production of heat.

The average CV[1] from the uncertainty test is 7,7%, which suggests robustness in

[1]Coefficient of variation = $\frac{\sigma}{\mu}$

the results.

4.2 Cradle-To-Gate IO-EA results interpretation

The Cradle-To-Gate IO-EA impact assessment uses the monetary value of 10 440 DKK_{1999} as being representative of 1 functional unit. Since the IO-EA analysis structure is *industry-based*, it is difficulty comparable with the LCA *process-based* results. Yet, an industry-process association has been attempted. It is described in details in Appendix D. Moreover, the reader must keep in mind that data is derived from technological performances observed during the 1995-1999 period.

Pollutant	Unit	Manuf.	Elect.	Transpt	Logist.	Heat	Total
GHG[a]	kg of CO_2 *eq.*	1 822	180,9	99,5	53,6	7,11	2 163
SO_2	kg	9,89	0,018	0,22	0,35	$1{,}71\times^{-3}$	10,48
NO_x	kg	9,34	0,35	0,46	0,16	$8{,}9\times^{-3}$	10,32
PM_{10}	kg	1,4	–	0,12	0,12	–	1,64
NMVOC	kg	19,81	–	0.4	0,14	$3{,}4\times^{-3}$	20,35

Table 4.2: IO-EA Impact Assessment results for one functional unit (10 440 DKK_{1999}). *Source: completed by the author.*

[a]from the 2007 IPCC GWP_{100a} characterisation model.

The results shown in Table 4.2 differ from those obtained through the LCA. However, there is a similar pattern in gas emissions when comparing the process trees: in terms of GHG emissions, polypropylene, electricity production and road and shipping supply are the most contributing factors. However, while GHG emissions identified through the IO-EA are 12% lower, SO_2, NO_x, PM_{10} and NMVOC figures are 101%, 215%, 679% and 600% higher, respectively. It is explained by the IO-EA broader system boundaries. Yet, this poses issues in regards to variability between the two models. Nevertheless, both sets of figures point to similar values ranges. Hence, to consider variability, two scenarios are used for the economic valuation analysis:

- a optimistic scenario, $Scenario_A$, including: GHG emissions from the IO-EA model and the SO_2, NO_x, PM_{10} and NMVOC figures from the LCA model,
- and a more pessimistic scenario, $Scenario_B$, including: GHG emissions from the LCA and the SO_2, NO_x, PM_{10} and NMVOC figures from the IO-EA model.

4.3 Economic valuation of damages

Figure 4.1 summarises the cost estimates for the manufacture of 1 t of white polypropylene-made nonwoven fabric, derived from the results presented in Tables 4.1 and 4.2.

Lower, central and upper estimates Significant differences appear wether lower, central or higher Climate change estimates are considered. It reflects on

Impact category	Parameters	Env. mechanisms	Endpoint impacts	Scenario A 10 440 DKK_{1999}	Scenario B 10 440 DKK_{1999}
Climate change	Lower estimate[1]	Radiative forcing	Costs due to adaptive and mitigating response to CC impacts	41,1€	50,53€
	Central estimate[2]		Costs due to CC impacts	147,08€	180,85€
	Higher estimate[3]		Costs due to CC impacts	614,3€	755,34€
Human health degradation	SVL 1M€	Formation of sulphate and nitrate aerosols and indirect formation of trop. ozone	Chronic and acute morbidity, mortality risk	45,49€	146,21€
	VLYL [50;75]k€				
Agricultural loss[4]		Deposition of SO_2, NO_x and formation of troposheric ozone	Biochemical and physiological negative effects (fertilizing effect incl.)	2,86€	14,26€
Material losss[4]		Enhances natural weathering effect	Corrosion of organic, inorganic and metallic materials	1,54€	3,13€
Total					
with Climate change lower estimate				90,99€	214,13€
with Climate change central estimate				**196,97€**	**344,45€**
with Climate change higher estimate				664,19€	918,94€

[1]abatement costs to reach Kyoto 2012 conditions. *Source: FUND project, version 2.8*
[2]with SRTP=1,5% (PRTP=0%, μ=1% and g=1,5%). *Source: Downing et al. 2005*
[3]with SRTP=0% (PRTP=0%, μ=1% and g=0%). *Source: Downing et al. 2005*
[4]*Source: Bickel and Friedrich, 2005 (2005 ExternE methodology)*

Figure 4.1: Climate change, human health degradation, agricultural and material loss cost estimates for the manufacture of one functional unit

totals, with the $Scenario_A$ lower and upper estimates being 54% lower and 237% higher than the central estimate, respectively. Differences are weaker in $Scenario_B$, but remain important. Climate change lower, central and upper estimates influence greatly the results.
For the following of this analysis, the $Scenarios_A \& _B$ with Climate change central estimate figures are used, as [Downing(2005)] shows that most of the 104 GHG economic valuation estimates tend to get close to the 68€/t of CO_2 *eq.* value.

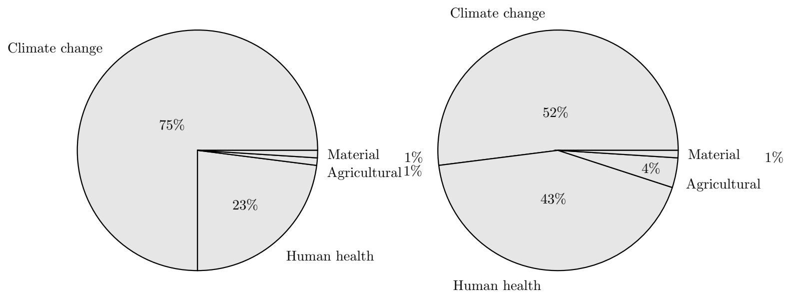

Figure 4.2: Scenario A & B impact categories costs composition, in percentage.

Process-based economic impacts It is interesting to visualise the processes impacting the most the Cradle-To-Gate value chain of the product. Figure 4.3 illustrates $Scenario_A \& _B$ economic impact for each life cycle stage considered. Costs related to heat have not been represented since their contributions remain marginal (≤0,5%).

$Scenario_A$* vs. *$Scenario_B$ $Scenario_A$ gives more importance to Climate change damage costs, with agricultural and material loss managing a merely 2%. Indeed, the IO-EA inventory identifies important quantities of GHG releases – notably for CO_2, CH_4 and N_2O – in comparison to other air pollutants identified by the LCA inventory – SO_2, NO_x, PM_{10} and NMVOC.
As for $Scenario_B$, although higher, Climate change cost figures are given less importance in regards to other air pollutants identified by the IO-EA inventory.

Whether it be $Scenario_A$ or $Scenario_B$, the manufacture process clearly dominates in all impact categories. Electricity and transport processes costs in $Scenario_A$, lower than in $Scenario_B$ in absolute terms, have comparatively more importance. Logistics-related impacts remain minors.
Figure 4.2 leads to think that priority should be set on internalizing environmental externalities occurring during the manufacture, electricity production and transport processes.

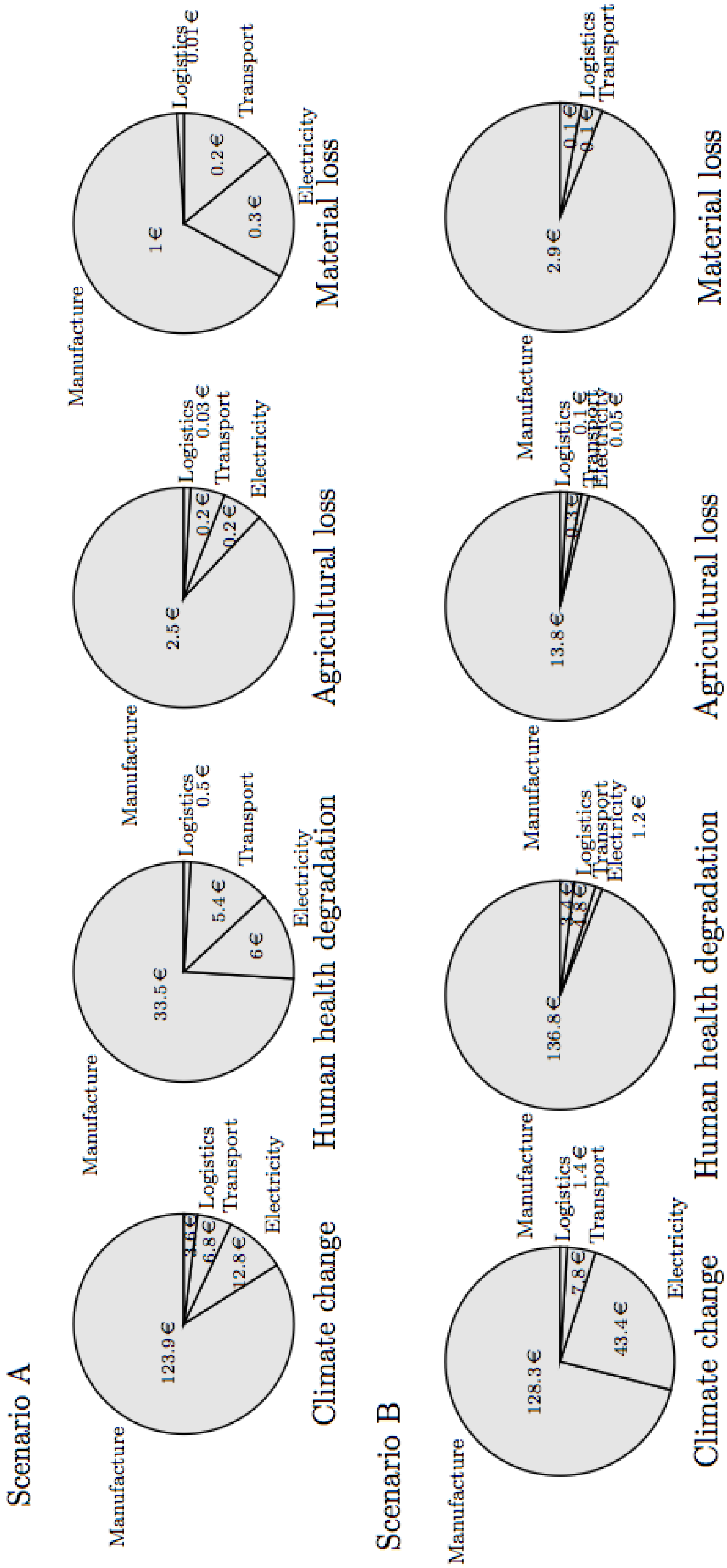

Figure 4.3: Processes contribution in economic environmental impacts

4.4 Economic integration of environmental externalities

The comparison between $Scenarios_A \& _B$ estimates and the expected taxes income levied in Denmark for the same year is shown in Table 4.3. It clearly appears that in all but transport and heating-related processes, the taxes levied do not cover the potential damage cost estimates. While taxes on emissions originating industrial-related processes may cover up to 87% of the estimated environmental costs (in reference to $Scenario_A$), the taxes levied from logistics-related processes cover only 22 to 27%. It is worth noticing that the energy tax occupies a significant share in the total amount of taxes levied.

The reasons for such difference between the amount of taxes levied and the estimated environmental costs are several:

- Limitations in the analysis:
    1. Only the values from the LCA inventory are used to calculate taxes income. Averaging LCA/IO-EA inventory values would have been more adequate and given probably higher emissions of SO_2 and NO_x,
    2. Most of the emissions behind the production and distribution of heat, is associated with waste incineration. Hence, only a small fraction appear in the Heating category. Additionally, waste incineration-based district heating is virtually GHG-free and does not have any tax counterpart.
    3. PSO[1] taxes are not included in this analysis. It is estimated to be 6% of the sale price of 1 kWh,
- Limitations in the policy design:
    1. MP_{10} and NMVOC-related damages do not have any tax counterpart,
    2. Energy intensive processes, such as power generation, benefit from a discounted tax rate on energy use – down to 0€/GJ in the case of power plants.

The transport-related processes, however, differ from such conclusion, as the taxes levied widely exceed the environmental cost estimates (up to 521%). This is largely due to a high energy tax rate on gasoline and diesel for vehicles.

[1] Public Service Obligation tax, on electricity sales. It aims at raising funds to support R&D programs in the development of renewable sources of energy.

I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*
Source	Energy tax rate	Amount	CO_2 tax rate	Amount	NO_x tax rate	Amount	SO_2 tax rate	Amount	Total	Env. cost estim.	Difference
	€/GJ	€	€/GJ	€	€/GJ	€	€/GJ	€	€	€	[X/XI] %
Industrial processes											
Light fuel oil	0,6	23,7	1,5	59,1	0,04	1,6	0	0			
Natural gas	0,6	12,6	1,2	25,2	0,03	0,6	0	0			
Coal	0,6	0,9	2	3	0,07	0,1	0,3	0,4	139,3	160,9–281,8[1]	49–87[2]
Lignite[3]	0	–	0	–	0,07	≤0,01	0,2	≤0,01			
Net Electricity[4]	0,97	3,59	2,3	8,51	0	–	0	–			
Logistics processes[5]											
Light fuel oil	0,6	0,1	1,5	0,3	0,04	0,01	0	0			
Natural gas	0,6	0,09	1,2	0,2	0,03	≤0,01	0	0			
Coal	0,6	0,03	2	0,1	0,07	≤0,01	0,3	0,01	1,1	4,14–5	22–27
Lignite	0	–	0	–	0,07	≤0,01	0,2	≤0,01			
Net Electricity	0,97	0,07	2,3	0,17	0	–	0	–			
Power generation											
Special agreement	0	–	0	–	0-0,3	–	0-0,7	–	10,89[8]	19,3–44,65	24–56
No special agreement[6]	0	–	1,2–19,9[7]	9,7–160,6	0–0,3[7]	0–2,4	0–0,7[7]	0–5,6			
Transport											
Gasoline	15,9	53,9	1,5	5,2	0,03	0,01	0	–			
Bio-gasoline[9]	15,9	0,12	0	–	0,03	≤0,01	0	–			
Diesel	9,3	–	1,5	–	0,04	–	0	–	65,7	12,6–13	505–521
Bio-diesel[10]	9,3	–	0	–	0,04	–	0	–			
Net Electricity	26,8	5,9	2,3	0,5	0	–	0	–			
Heating											
Light fuel oil	7,7	0,3	1,5	0,06	0,04	≤0,01	0	–			
Natural gas	7,7	0,2	1,2	0,03	0,03	≤0,01	0	–			
Coal	7,7	0,18	2	0,05	0,07	≤0,01	0,3	–	0,82	0,63–0,47	130–174
Lignite	0	–	0	–	0,07	–	0,2	–			
Net electricity	22,6	–	2,3	–	0	–	0	–			

Table 4.3: Expected environmental and energy taxes levied from the manufacture of 1 t of white polypropylene-based nonwoven fabric in Denmark in 2011. *Source: SkatteMinisteriet, 2010. Completed by the author.*

[1] Cost $\text{estimate}_{\text{ScenarioA}}$–Cost $\text{estimate}_{\text{ScenarioB}}$

[2] $[X/XI_{Sc.B}]$–$[X/XI_{Sc.A}]$

[3] And other types of biomass fuels, *e.g.* wood, wood scraps, straw

[4] A inefficiency rate of 41,3% in the electricity production process is initially assumed, where 1,413 GJ of distributed electricity gives 1GJ of useful electricity. It give a energy tax rate of 0,4€/GJ of gross electricity or 0,97€/GJ of net electricity.

[5] Industrial processes taxation rates apply.

[6] Because information regarding wether or not power plant units in the LCA model are under the special quota agreement regarding energy and environmental taxes with the Danish Tax Ministry is missing, it is assumed none of them have.

[7] Because several parameters may condition the taxation levels for power plant units, approximate ranges of tax rates for CO_2, SO_2 and NO_x are shown. However, [SkatteMinisteriet(2010)] recommends a median value of 1,35€/GJ of electricity produced, all gases emissions taken together. This rate is used in the 10th column, Total.

[8] Because of large variation in the tax rates, a rate of 1,35€/GJ of electricity produced, all gases emissions taken together is used.

[9] Biofuel to be mixed with gasoline.

[10] Biofuel to be mixed with diesel.

5

Conclusion

5.1 Interpretation

The technical limitations of this study are numerous:

- the LCA analysis, although known and corrected, observes uncertainty in the end-results,
- the LCA model does not consider the gas emissions behind the production of heat being associated with the supply of heat but with the incineration of waste,
- the IO-EA is highly aggregated and makes the allocation of environmental burden between process categories (manufacture, logistics, heating and transport) uncertain,
- because of industrial secrecy, the value of 10 440 DKK_{1999} as a functional unit for the IO-EA analysis remains uncertain,
- the lower, central and upper estimates related to Climate change are widely varying from each other. The central estimate of 68€/t of CO_2 *eq.* is only a best-guess value stemming from 104 reviewed estimates studies. The contribution of Climate change costs in the final estimate is very important,
- the economic values for human health impairment rely heavily upon parameters obtained through individuals' preferences (aversion for risk, Willing-To-Pay, Social Rate of Time Preference, Value of Statistical Life,...),
- the use of the *Energy Cumulative Demand* measurement is methodologically incorrect. Only the *useful* energy should be applied to tax rates. Instead, the *Cumulative Energy Demand* forced the analysis to include the primary energy as well, slightly overestimating the taxes levy total income – especially in regards to the power generation-

related processes.

- the inability to use IO-EA to estimate the *Energy Cumulative Demand* forced the analysis to rely exclusively upon the LCA energy streams.

Yet, it is still reasonable to conclude that the Danish "green" and energy regulatory taxes system does not fully integrate the costs given by the economic valuation of environmental damage given by $Scenarios_A\&_B$.

The energy and CO_2 taxes on gasoline for transportation processes cover fairly well for the resulting environmental degradation. However, the combustion of light fuel, natural gas and coal in manufacture-related processes is not sufficiently taxed so as to compensate for the direct and indirect damage. The same remark holds for electricity production and other energy-intensive industries, which benefits up to a 90% discount on rates (down to 0€/GJ for the energy tax). This is a strategical move to secure their competitive advantage as German and British taxes for energy-intensive industries are higher. Eventually, PM_{10} and NMVOC-related externalities do not have any compensation mechanism.

Why and how to reveal environmental externalities?

This study, using *Ecological Economics* axioms, shows the importance of quantifying and assessing environmental externalities to integrate them into market mechanisms. Indeed, unaccounted environmentally harmful practices become external to market mechanisms and stakeholders' knowledge. It inevitably leads to inefficient transaction outputs, with "hidden" environmental costs indirectly borne by the society as a whole.
This study also shows that tools originating *Industrial Ecology* may be used to reveal harmful environmental mechanisms. The use of two LCI datasets about nonwoven fabric production in Denmark, processed by LCA and IO-EA, allowed to quantify industrial-environment interactions, notably gas and particles emissions (GHG, SO_x, NO_x, MP_{10} and NMVOC).

How to value environmental externalities?

The second chapter stresses the importance of valuing the externalised environmental degradation, in order to integrate them into the value chain of the product. It is thought to be a means by which it is possible to alter stockholders' preferences, and eventually, reach transaction outputs reflecting the true cost of the product. This study monetizes these externalities using economic valuation factors provided by different European studies (ExternE and FUND), in regards to the following impact categories: climate change, human health impairment, agricultural and material loss. For one functional unit (1 t of nonwoven fabric in Denmark in 2011), optimistic and pessimistic cost estimate scenarios are derived (ranging from 197€ to 345€) with manufacturing operations being the most contributing processes and climate change the largest cost category (along with human health degradation).

How to internalize environmental externalities?

Following the case of nonwoven fabric, the direct fiscal instruments used by the Danish government to regulate harmful gas emissions is used to estimate taxes levy upon the production of one functional unit. This tax levy estimate is compared to the monetization of environmental externalities obtained previously. It allows not only to assess how "well" the "green" taxes system covers for environmental degradation originating the nonwoven production, but also highlights hotspots within the value chain which lack of tax counterpart. It is the case with MP_{10} and NMVOC emissions or emissions originating electricity production. Yet, regarding electricity production, LCA and IO-EA show that significant amount of energy are embodied in raw materials necessary to the nonwoven production. A high taxation level may therefore have heavy consequences vis-à-vis the market competitiveness abroad. This technique of combing impact assessment tools with economic valuation of environmental degradation factors is believed to constitute supporting tools for "green" fiscal policy design.

This technique has shown that hydrocarbons, although widely processed in today's society, are still the source of important degradation being only partially internalized. Hence, suggestions regarding policy design are made in the two following sections.

5.2 The need for environmental policy

Denmark is a pioneer in promoting the *economic growth-environmental degradation* decoupling objective. Although much of its efforts have been focused on *command-and-control instruments* – direct intervention through *pigouvian* taxes mainly – it has also undertaken indirect intervention through legislation – *e. g.* the imposition of *de-sulphurisation* units in power plants – and has been the first European country, along with the United Kingdom, to undergo the Phase I test of the European Union ETS[1], covering energy-intensive industries and power

[1] Emissions Trading Scheme

plants[1].

Denmark has fully understood the importance of a well designed environmental policy, as it totally conditions its effectiveness. Environmental taxes have, as [Andersen(2005)] puts it, a *double dividend* potential. Indeed, they produce stimulus that incite businesses in innovating, coming up with cleaner technologies and becoming more *resource efficient*, but also in minimising harmful environmental mechanisms. An analogy can be made here between *Industrial Ecology*'s view of an entity responding to its environment constraints and resources scarcity and businesses responding to "green" taxes, which, after all, reflect environmental (pollution) and resources (fossil-fuels) constraints too.

It is believed that direct fiscal instruments aiming at internalizing externalities in the market prices may achieve this *double dividend*. Studies show that in Denmark, as a result from "green" taxes from 1993 to 2000, industries CO_2 emissions have already decreased by 25% [Andersen(2005)]. The application of new technologies and pollution prevention solutions is more and more frequent. The use of new less carbon-intensive fuels and energy saving practices largely explain these statistics [Enevoldsen(2005)].

5.3 Final remarks

Results show that taxes only partially cover for environmental damages, considering all assumptions behind the figures. Yet, the level of taxation on energy use and harmful gas emissions remains relatively high, in regards to other practices in Europe. It levies an estimated 217€ per ton of nonwoven produced in 2011 (against a cost estimate $Scenarios_A \&_B$ interval of 197–345€).
While it may be desirable from an environmental point of view to increase the taxes so as to cover completely the externalities cost estimate, this may bring about economical negative long term effects – *i. e.* decrease of competitiveness on international markets and others – if this political will is not followed by other countries – *i. e. free ride*. Pressures from abroad are economically very important and may impede the political will for a strong environmental regulation. Yet, environmentally-wise, air pollution does not know any borders.

Still, if this set of "green" and energy taxes may partially account for and reduce the amount of negative *economy-environment* interactions by affecting producers and consumers' preferences, the very nature of these environmental taxes may be questioned since they do not constitute financial reserves to guarantee the potential environmental degradation

[1] However, the latter returned being only limited results, as flaws in the system design led to more emissions allowance allocations than the actual emissions, driving the permits price down to 0€.

compensation. Indeed, only a fraction of this income is destined to support adaptive measures – *i.e.* subsidies for "green" investments – while the main part is recycled into labour taxes reduction. The recycling of these taxes into compensation funds and subsidies to benefit climate change action programmes, the national social security system as well as land owners and building renovation initiatives should be envisaged to fully enforce the environmental aspect of these instruments.

Finally, a econometric analysis is needed to estimate the optimum level of taxation before consumers' substitution effect shifts the demand in favour of less expensive products – similar products originating a country where "green" and energy taxes are lower or inexistent – or a substitute product which scores very low in another impact category not considered here.

References

[Agency(2001)] Nuclear Energy Agency. Externalities and energy policy: The life cycle analysis approach. Technical report, Organisation For Economic Co-Operation And Development, 2001. 11

[Andersen(2005)] Mikael Skou Andersen. Do "green" taxes work? *National Environmental Research Institute of Denmark*, 2005. 40

[Assessment(2005)] Millenium Ecosystems Assessment. Ecosystems and human well-being: General synthesis. Technical report, 2005. 2

[Ayres and Kneese(1969)] R.U. Ayres and A.V. Kneese. Production, consumption and externalities. *American economic review*, 59:282–297, 1969. 5

[Bickel and Friedrich(2005)] Peter Bickel and Rainer Friedrich. *Externalities of Energy: Methodology 2005 Update*. Institut für Energiewirtschaft und Rationelle Energieanwendung, 2005. 9, 24

[Binswanger(1993)] M. Binswanger. From miscroscopic to macroscopic theories. *Journal of Ecological Economics*, 8:209–234, 1993. 5

[Boulding(1950)] K.E. Boulding. A reconstruction of economics. *Wiley*, 1950. 5

[Commission(2001)] European Commission. Green paper on integrated product policy. Technical report, Commission of the European Communities, 2001. 11

[Constanza(2001)] Robert Constanza. Visions, values, valuation, and the need for an ecological economics. *Journal of Bioscience*, 51(6):459–468, 2001.

[Daly(1968)] Herman Daly. On economics as a life science. *Journal of Political Economy*, 76:392–406, 1968. 5

[Daly(1994)] Herman Daly. Fossil fuels. *Journal of Applied Energy*, 47:101–121, 1994. 1

[Denmark(2011)] Statistics Denmark. Varer1: Industrial commodity statistics by commodity group and unit (annual). commodity number: 5503400000, 2011. URL `http://www.statistikbanken.dk/statbank5a/default.asp?w=1280`. 18, 20

[Downing(2005)] Thomas E Downing. Social cost of carbon: A closer look at uncertainty. 2005. 22, 23, 32

[Enevoldsen(2005)] Martin Enevoldsen. *The Theory Of Environmental Agreements And Taxes*. Edward Elgar Publishing, 2005. 40

[Enquete-Kommission(1994)] Enquete-Kommission. schutz des menschen und der umwelt": Die industriegesellschaft gestalten. 1994. 1, 14

[ExternE(1995)] ExternE. Externalities of energy. Eur 16520 en, European Commission, 1995. 13

[ExternE(2006)] ExternE. Simplified ecosense model, 2006. URL `http://ecoweb.ier.uni-stuttgart.de/ecosense_web/ecosensele_web/frame.php`. 25, 26

[Georgescu-R(1971)] N. Georgescu-R. The entropy law and the economic process. *Harvard University press*, 1971. 5

[IPCC(2007)] IPCC. Climate change 2007: The physical science basis. contribution of working group i to the fourth assessment report of the intergovernmental panel on cli mate change. Technical report, Solomon, S. and D. Qin and M. Manning and Z. Chen and M. Marquis and K.B. Averyt and M. Tignor and H.L. Miller, 2007. 2

[Kronenberg(2007)] Jakub Kronenberg. *Ecological Economics and Industrial Ecology*. Routledge, 2007. 6

[Risi(2012)] Risi. Nonwoven markets price watch, 2012. URL `http://www.risiinfo.com/risi-store/do/product/detail/nonwovens-markets.html`. 20

[Sacchi(2012)] Romain Sacchi. Carbon footprint assessment of nonwoven fabric. Technical report, Fibertex Personal Care, 2012. 16, 18, 47

[Schwermer(2007)] Sylvia Schwermer. Economic valuation of environmental damage. Technical report, Federal Environment Agency, 2007. 14, 15, 24, 45

[SkatteMinisteriet(2010)] SkatteMinisteriet. Energiafgift for erhverv og konkurrenceevne. Technical report, SkatteMinisteriet, 2010. 27, 35

[SkatteMinisteriet(2011)] SkatteMinisteriet. Income list 2011, 2011. URL `http://www.skm.dk/public/regneark/Indtaegtsliste2011.xls`. 27

[Wiera(2005)] Mette Wiera. Are co2 taxes regressive? evidence from the danish experience. *Journal of Ecological Economics*, 52:239–251, 2005. 27

Appendix A

Methodological Convention standardized procedure

The procedure down below is provided by the document: Methodological Convention for Estimates of Environmental Externalities [Schwermer(2007)], pp.50. It recommends a standardized procedure to follow for economic valuation of environmental damage. Chapter 4, *The case of nonwoven fabric in Denmark*, which deals with the economic valuation of environmental damage due to the manufacture of nonwoven fabric in Denmark, tries to follow this structure.

A. METHODOLOGICAL CONVENTION STANDARDIZED PROCEDURE

	Valuation steps	
1	Description of the aim of the valuation	
2	Specification of the subject of analysis and of system boundaries with regard to ➢ Responsible actor / activities ➢ Sources of environmental impacts ➢ Types of damage to be analyzed, environmental impact on protected goods ➢ Regional, temporal, project-related system boundaries etc..	
	Physical impact pathway	***Monetary valuation***
3	Description of relevant sources of environmental impacts	
4	Description of cause-effect relationships (impact assessment)	
5	Assignment to economic utility and cost categories	
6		Economic valuation of the resulting changes in utility for humans
7	Description and interpretation of results in the context of the aim set (if applicable, comparison of environmental damage costs with costs already internalized)	

Figure A.1: Standardized procedure for economic valuation of environmental damage. *Methodological Convention for Estimates of Environmental Externalities, Schwermer, 2007.*

Appendix B

LCA model parameters

Down below is shown the life cycle model parameters and inventory provided by the study of [Sacchi(2012)], used as a basis for the LCA figures.
This LCI is a part of more complete LCA (Carbon Footprint Analysis) performed for a Danish nonwoven mill, Fibertex Personal Care. The full report concerning the LCA conducted for Fibertex Personal Care is available in Appendix F. This LCI covers a decade of production (2001-2010) as well as 60% of the annual national volume.

Figure B.1 shows the model parameters, conditions, assumptions, scope, etc. Figure B.2 shows the resulting Inventory. Table B.1 lists the gaseous emissions collected through the inventory.

B. LCA MODEL PARAMETERS

Goal and Scope of analysis – summary table

Goal of the analysis

Use

Report the environmental degradation – in terms of potential global warming contribution – linked with the conception, transformation, manufacture and packaging of white spunmelt non-woven fabric

Aim

Identification of hotspots in the Fibertex Personal Care value chain of non-woven fabrics
Support and guide future product re-design and engineering initiatives
Help making a selection of environmental indicators for future monitoring surveys
Promote the environmental performance of Fibertex Personal Care products

Audience

External non-specialist audience
Fibertex Personal Care partners (suppliers, customers)
Fibertex Personal Care direction board

Scope of the analysis

Functional unit

1 t of white spunmelt non-woven fabric

System boundaries

Cradle-to-Gate, year 2011

Data inventory method

Mass Flow Accounting: input of materials and non-materials (raw/ancillary materials, energy and water), output of materials and non-materials (products, by-products, emissions to air, water and soil). Domestic used/unused extraction, indirect flows associated to imports/exports and stock accumulations neglected.

Impact assessment method

Single impact category: Climate
Entirety of greenhouse gases associated to the impact category Climate change
IPPC GWP100a characterization factors, over a 100 years time horizon

Allocation procedures

The entirety of resources use within Fibertex Personal Care facilities and consequent environmental degradation is associated to the product system
Exceptions: district heating supply (allocation to landfill), energy recovery and recycling (benefits considered as avoided additional production)

Value choices

Carbon Footprint Analysis. Neglects other impact categories
White spunmelt non-woven fabric. Neglects other colored products
Cradle-to-Gate scope. Neglects other product life cycle phases

Assumptions

Hydrophilic surfactant chemical composition: 87% water, 13% oil lubricant
Stocks accumulation explains dissymmetry between supply and consumption of materials
Water content of finished products: 0%
Most of resources consumption patterns follow a normal or log-normal statistical distribution
Gas burners as industrial furnaces without NO_x reduction feature
Mini CHP plant in Swiss considered similar in performances as Aalborg Reno-Nord CHP plant
PlasticsEurope dataset to assess PP manufacture

Data quality requirements

Semi-quantitative framework for quality assessment
Minimum quality indicators score required: 10/15 for Validity of data, 10/15 for Validity of the model, 10/15 for Reliability of data, 10/15 for Reliability of the model, 27/40 for Procedure
Minimum Overall Quality score required: 70/100

Limitations

Relevant environmental impact categories discarded. Limited to Carbon Footprint Analysis
Distribution, use and disposal product life cycle phases discarded
Capital equipment material and energy needs discarded. Limited to a second-order energy analysis (material and energy needs of capital equipment ignored)

Figure B.1: LCI model parameters

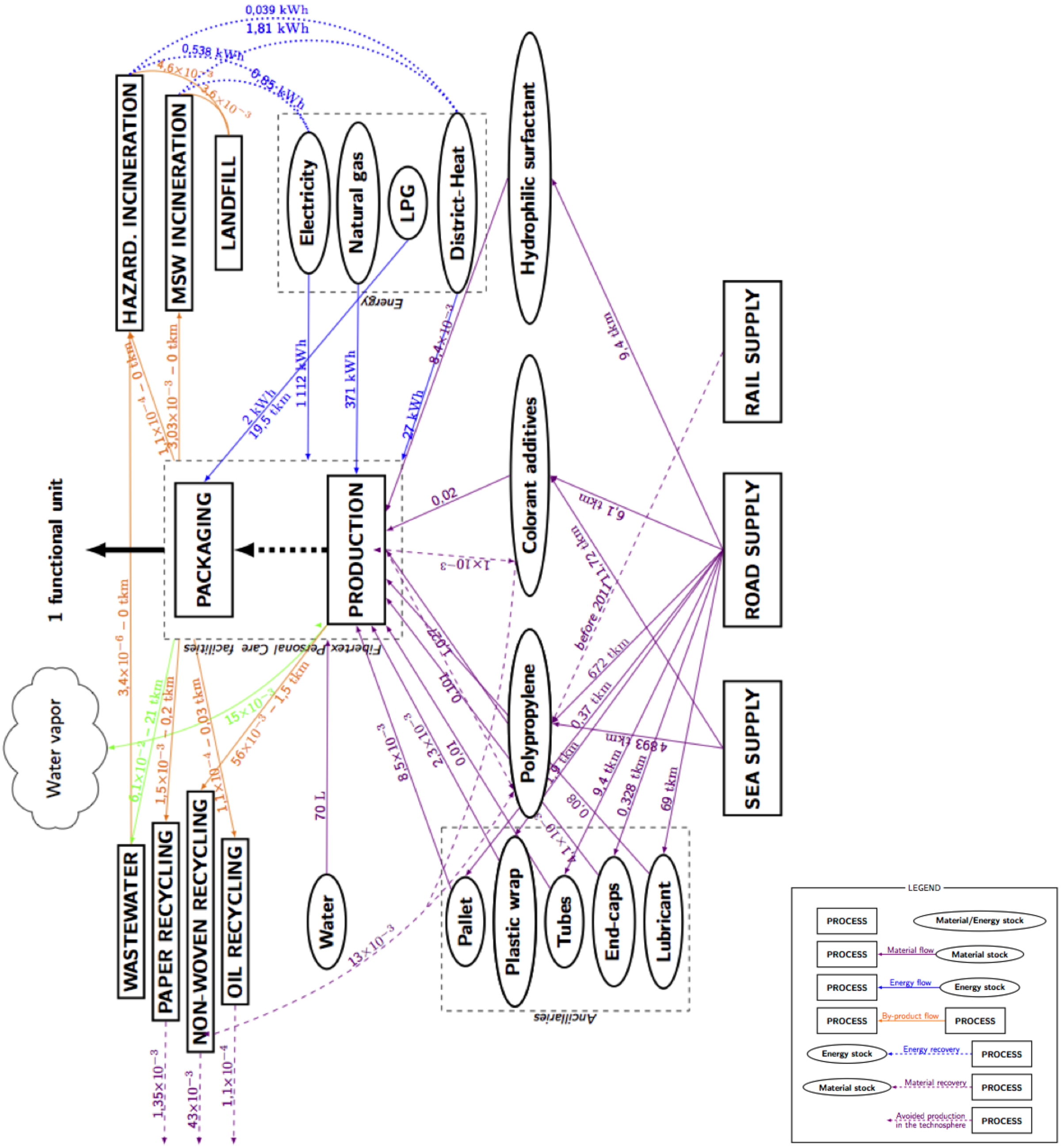

Figure B.2: LCI graphical representation from LCA

	Mole fractions in 2005	Inventoried emissions within the product system boundaries in 2011
CO_2*	379 ±0,65 µmol/mol	2 312 kg
CH_4*	1,774 ±1,8 nmol/mol	13 kg
N_2O*	319 ±0,12 nmol/mol	38 g
HFC-134a*	35 ±0,73 pmol/mol	267 mg
SF_6*	5,6 ±0,038 pmol/mol	51 mg
HCFC-22*	169 ±1 pmol/mol	20,7 mg
CF_4*	74 ±1,6 pmol/mol	1,86 mg
CCL_4*	93 ±0,17 pmol/mol	1,14 mg
C_2F_6*	2,9 ±0,025 pmol/mol	222 µg
CFC-12*	538 ±0,18 pmol/mol	13,4 µg
CFC-11*	251 ±0,36 pmol/mol	6,13 µg
HFC-152a*	3,9 ±0,11 pmol/mol	4,09 µg
CH_3CCL_3*	19 ±0,47 pmol/mol	537 ng
HFC-23*	18 ±0,12 µmol/mol	400 ng
CFC-113*	79 ±0,064 pmol/mol	232 ng
HCFC-141*b	18 ±0,068 pmol/mol	–
HCFC-142b*	15 ±0,13 pmol/mol	–
HFC-125*	3,7 ±0,1 pmol/mol	–
SO_2	–	5,21 kg
NO_x	–	4,82 kg
MP_{10}	–	0,296 kg
NMVOC	–	3,56 kg

Table B.1: LCI of gaseous emissions from LCA. Gases with a * are officially recognized by the 2007 IPCC GWP_{100a} characterization model as GHG.

Appendix C

IO-EA model parameters

Down below is shown the life cycle model parameters and Inventory provided by Denmark Statistics and 2.-0 Consultants collaboration: Input-Output table with Environmental Accounts for Denmark 1999, used as a basis for the IO-EA figures.
This LCI covers the statistics observed in Denmark during the period 1995-1999, describing the national industrial outputs triggered by the marginal production of 10 440 DKK_{1999} of nonwoven synthetic fabric.

Figure C.1 shows the model parameters, conditions, assumptions, scope, etc. Figure C.1 shows the resulting Inventory under the form of a process tree, generated by the LCA software SimaPro. Table C.2 lists the gaseous emissions collected through the inventory.

Goal and Scope of analysis – summary table

Goal of the analysis

Use

Report the environmental elementary flows – in terms of gaseous emissions – linked with the conception, transformation, manufacture and packaging of white SMS nonwoven fabric and the connected industrial sectors.

Aim

Identification of hotspots in the nonwoven fabric value chain.
Quantify gaseous emissions for a further assessment of environmental impacts.
Analyzsis the environmental performances of nonwoven fabric.

Audience

External specialist and non-specialist audience.

Scope of the analysis

Functional unit

10 440 DKK_{1999} of white SMS nonwoven fabric.

System boundaries

Cradle-to-Gate scope, period 1995-1999, within Denmark borders.

Data inventory method

Mass Flow Accounting: input of materials and non-materials (raw/ancillary materials, energy and water), output of materials and non-materials (products, by-products, emissions to air, water and soil). Domestic used/unused extraction, indirect flows associated to imports/exports and stock accumulations neglected.

Impact assessment method

Entirety of greenhouse gases associated to the impact category Climate change.
Environmental characterization with IPPC GWP100a characterization factors, over a 100 years time horizon.
Economic characterization with valuation model from Downing et al. 2005, over a 100 years time horizon.
Other non-greenhouse gases are collected without environmental characterization models - SO_2, NO_x, MP_{10} and NMVOC and processed with economic valuation models, provided by ExternE, 2006.

Allocation procedures

The entirety of resources used is associated to the product system, including intermediaries resulting from round-by-round effect.

Value choices

Cradle-to-Gate scope. Neglects other product life cycle phases.

Assumptions

Imported goods manufacture efficiency rates, notable emissions factors, are derived as proxies from USA IO-EA tables, and are supposedly reflecting average European efficiency rates.

Data quality requirements

The sets of statistics data have been externally reviewed by several third parties.

Limitations

Other relevant environmental impact categories discarded. Limited to Climate change, human health, agricultural and material degradation impacts.
Distribution, use and disposal life cycle phases discarded, because of a Cradle-To-Gate limited scope.
Industries characterized by the production of one good only.
Flows highly aggregated: process-level analysis rendered difficult.
Industry-level analysis: association with specific processes unclear.
Some GHG emissions are not identified.

Table C.1: IO-EA LCI model parameters

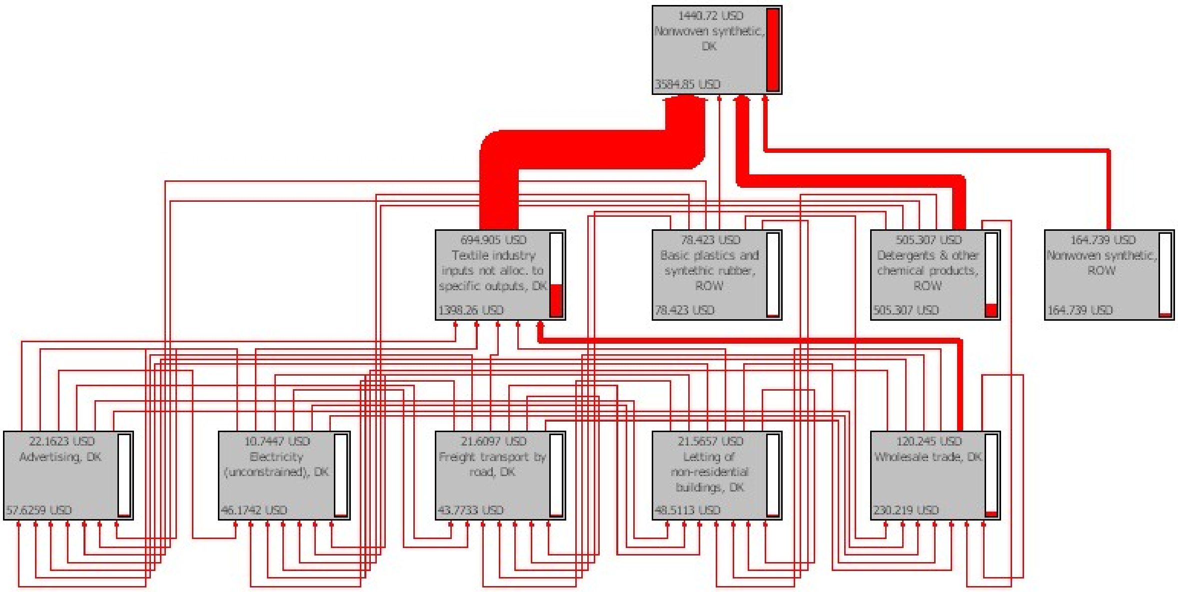

Figure C.1: IO-EA product system representation. How to read this diagram: material flows are expressed in USD (with 7,25 DKK for 1 USD). The thickness of arrow flows represent their relative importance in the product system. Arrows leaving from one block and coming back to the same block refer to the looping effect (or *round-by-round* effect).

	Mole fractions in 2005	Inventoried emissions within the product system boundaries in 2011
CO_2*	379 ±0,65 µmol/mol	1 931 kg
CH_4*	1,774 ±1,8 nmol/mol	7,7 kg
N_2O*	319 ±0,12 nmol/mol	131,8 g
HFC-134a*	35 ±0,73 pmol/mol	–
SF_6*	5,6 ±0,038 pmol/mol	–
HCFC-22*	169 ±1 pmol/mol	–
CF_4*	74 ±1,6 pmol/mol	–
CCL_4*	93 ±0,17 pmol/mol	–
C_2F_6*	2,9 ±0,025 pmol/mol	–
CFC-12*	538 ±0,18 pmol/mol	–
CFC-11*	251 ±0,36 pmol/mol	–
HFC-152a*	3,9 ±0,11 pmol/mol	–
CH_3CCL_3*	19 ±0,47 pmol/mol	–
HFC-23*	18 ±0,12 µmol/mol	–
CFC-113*	79 ±0,064 pmol/mol	–
HCFC-141*b	18 ±0,068 pmol/mol	–
HCFC-142b*	15 ±0,13 pmol/mol	–
HFC-125*	3,7 ±0,1 pmol/mol	–
SO_2	–	10,48 kg
NO_x	–	10,32 kg
MP_{10}	–	2,06 kg
NMVOC	–	20,35 kg

Table C.2: IO-EA inventory of gaseous emissions. Gases with a * are officially recognized by the 2007 IPCC GWP_{100a} characterization model as GHG. In comparison to the LCA Inventory, it can be seen that a significant amount of GHG gases are not identified.

Appendix D

Industry-process association

The impact assessment results given by the IO-EA analysis are presented on an industrial sectors basis. In order to re-use these findings and combine them with those found through the LCA impact assessment results, it is necessary to express them on a process-based basis. However, this may prove to be difficult, since the flows are highly aggregated. Hence, uncertainty remains as to which industry do processes belong to. An industry-processes association has been attempted. Table D.1 shows how industry outputs and their respective gaseous emissions from the IO-EA impact assessment have been associated to different processes.

D. INDUSTRY-PROCESS ASSOCIATION

IO-EA industry outputs	Manufacture	Electricity	Transport	Logistics	Heat
Detergents and other chemicals	•				
Nonwoven synthetic	•				
Basic plastics and synthetic rubber	•				
Textile industry	•				
Pigments	•				
Starch	•				
Rubber products	•				
Pulp, paper	•				
Refined petroleum products	•				
Wholesale trade	•				
Textile industry inputs	•				
Plastic products	•				
Electricity, unconstrained		•			
District heating					•
Crude petroleum		•			
Gas		•			
Electrical machinery		•			
Electricity, ROW		•			
Waste incineration		•			
Freight transport, by road			•		
Transport by ship			•		
Air transport			•		
Marine engines			•		
Air transport, ROW			•		
Motor vehicles			•		
Basic, non-ferrous metals			•		
Basic, ferrous metals			•		
Iron and steel			•		
Fertilizers			•		
Wood products			•		
Paints			•		
Iron after first processing			•		
Vegetables and animal fats			•		
Horticultural products			•		
Processed fruits			•		
Cofee, tea			•		
Machinery for industries				•	
Hand tools, metal packaging				•	
General purpose machinery				•	
Concrete				•	
Office machinery				•	
Radio & Communication				•	

Table D.1: Association between IO-EA industry outputs and process categories

Appendix E

Denmark environmental taxes - Spring package 2.0

Down below is shown the environmental taxes structure currently applied in Denmark. The tax rates are based upon gases emissions and are expressed in DKK/GJ (4^{th}, 5^{th} and 6^{th} columns). They are also expressed as an average per quantity of energy used (3^{rd} column). It give an equivalent 155,4 DKK/t of CO_2, 10 DKK/t of SO_2 and 5 DKK/t of NO_x. However, the application of these rates depend on the context of emissions (not all emissions from all type of industries are taxed). Additionally, they do not include the PSO tax, levied on electricity consumption.

Tabel III 2: Afgiftssatser for energi i 2010 eksklusive PSO

	Enhed	Energiafgift	CO_2-afgift	NO_x-afgift	SO_2-afgift	I alt
Til vejtrans-port mv.						
Fossil benzin	*Kr./GJ*	118,1	11,3	0,2	0	129,6
Biobenzin[1]	*Kr./GJ*	118,1	0	0,2	0	118,3
Fossil diesel	*Kr./GJ*	69,1	11,5	0,3	0	80,9
Biodiesel[1]	*Kr./GJ*	69,1	0	0,3	0	69,4
Elektricitet[2]	*Øre/kWh*	71,8	6,2[3]	0	0	78,0
Elektricitet netto	*Kr./GJ*	199,4	17,2	0	0	216,7
Elektricitet brutto[4]	*Kr./GJ*	82,4	7,1	0	0	89,5
Til rumvarme						
Fyringsolie	*Kr./GJ*	57,3	11,5	0,3	0	69,1
Naturgas	*Kr./GJ*	57,3	8,9	0,2	0	66,4
Kul	*Kr./GJ*	57,3	14,8	0,5	2[5]	74,6
Halm mv.	*Kr./GJ*	0	0	0,5	1,7[5]	2,2
Elvarme[2][6]	*Øre/kWh*	60,4	6,2[3]	0	0	66,6
Do netto	*Kr./GJ*	167,8	17,2	0	0	185,0
Do brutto[4]	*Kr./GJ*	69,3	7,1	0	0	76,4
Anden el[2]	*Øre/kWh*	71,8	6,2[3]	0	0	78,0
Do netto	*Kr./GJ*	199,4	17,2	0	0	216,7
Do brutto[4]	*Kr./GJ*	82,4	7,1	0	0	89,5
Til proces						
Fyringsolie	*Kr./GJ*	4,5[7]	11,5[8]	0,3	0	16,0
Naturgas	*Kr./GJ*	4,5[7]	8,9[8]	0,2	0	13,4
Kul	*Kr./GJ*	4,5[7]	14,8[8]	0,5	2[5]	21,8
Halm mv.	*Kr./GJ*	0	0	0,5	1,7[5]	2,2
El	*Øre/kWh*	2,6[9]	6,2[10]	0	0	8,8
Do netto	*Kr./GJ*	7,2	17,2	0	0	24,4
Do brutto[4]	*Kr./GJ*	3,0	7,1	0	0	10,1
Brændsler til elproduktion						
Inden for kvotesektoren	*Kr./GJ*	0	0	0-2	0–5	1[11]
Uden for kvotesektoren	*Kr./GJ*	0	8,9-148	0-2	0-5	10[11]

(1) Til sammenblanding med fossilt brændstof.
(2) Sats i 2011i 2010-niveau. I 2010 er satsen 5,9 øre/kWh lavere. El er indirekte belastet med SO_2- og NO_x-afgift i det omfang, der ved produktionen udledes NO_x og SO_2 og disse afgifter delvist overvæltes.
(3) Sats med hjemmel i CO_2-afgiftslov – er ikke en afgift på CO_2 og benævnes derfor energispa-reafgift.
(4) Under forudsætning af en virkningsgrad på 41,3 pct. ab forbruger.
(5) Varierer .
(6) Af forbrug udover 4.000 kWh i helårsboliger registreret som elopvarmede.
(7) Gælder ikke mineralogiske og metallurgiske processer samt primær jordbrug, hvor sats er nul. Fra 2013 15 kr./GJ Ved *Serviceeftersyn af Forårspakke 2.0* reduceres afgifter på proces i for-hold til det vedtagne. Ved ensartet nedsættelse af stigninger til godt 8 kr./GJ i 2013
(8) Gælder ikke for brændsel anvendt til proces samt elfremstilling inden for kvotesektoren, hvor satsen er nul
(9) Sum af eldistributionsbidrag på 1 øre/kWh, der gælder for forbrug op til 15 mio. kWh og energiafgift på 1,6 øre/kWh (fra 2013 5,9 øre/kWh i 2010-niveau), der ikke gælder mineralo-giske proces mv. Ved *Serviceeftersyn af Forårspakke 2.0* reduceres afgifter på proces i for-hold til det vedtagne. Ved ensartet nedsættelse af stigningen til ca. 3,2 øre/kWh fra 2013
(10) For let proces. For tung proces 2,6 øre/KWh. For tung proces med aftale 0,3 øre/kWh.
(11) I gennemsnit omkring 1 kr./GJ efter NO_x og svovlrensning inden for kvotesektoren og ca. 10 kr./GJ uden for kvotesektoren.

Figure E.1: Denmark environmental taxes on gas emissions, by type of energy and industry. *Source: Skatteministeriet, 2010*

Appendix F

Life cycle inventory of nonwoven fabric

The life cycle inventory of the nonwoven fabric production in Denmark in 2011 is provided by the author in a digital format. Although the version of this LCI and consequent LCA has not been certified ISO 14040-44 compliant during the writing of this work, a more definitive version, by July, will be released and fully compliant with the international norms.