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Transport and Industrial Ecology - Problems and Prospects

Ph.D. thesis

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Preface

This Ph.D. thesis is about transport and industrial ecology. The superior objective is to develop an understanding of relations between industrial ecology and transport, in terms of problems and prospects. Theoretical as well as empirical research approaches and materials are used.

The thesis is based on contributions from several research projects. They cover a period of 8 years, all with a prime focus on relations between industry, transport and the environment. In most of the projects I have had the function as project manager in combination with active researcher. Several other researchers have also contributed in these projects. Some of them are employed in the research group I am part of at Western Norway Research Institute. I am grateful for their contributions and in particular thankful for the constructive suggestions and critical comments from the group's Head of research, Karl Georg Høyer. In addition, without the valuable advices from my academic supervisor at Aalborg University, Associate Professor Arne Remmen, this thesis would not have become a reality.

In addition to the introduction and the conclusion chapter, the thesis consists of 6 main chapters. One is a theoretical contribution that is previously unpublished. Four chapters are all separate articles published, or submitted for publishing, in scientific journals. They are exactly in the form they have been published / accepted for publishing. The last main chapter is a conference paper with a separate set of notes. The texts in these notes were not included in the submitted paper due to restrictions regarding the length of the paper. They are included to give a more complete presentation, both of the theoretical and empirical material the paper is based on.

Sogndal, Norway
March 2003

Otto Andersen

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SUMMARY

This thesis is about relations between *industrial ecology* and *transport*. The thesis addresses how *problems* connected to transport is understood within the frame of industrial ecology. In particular the thesis deals with transport problems in different understandings of industrial ecology. The superior goal is to develop understanding of the relations between transport and industrial ecology. Both theoretical and empirical research approaches and material are used. Theoretically by the development of a *typology* of different understandings of industrial ecology. Empirically through analyses of *cases* with basis in results from several *research projects* carried out at Western Norway Research Institute over a period of about 8 years. They are all projects with prime focus on relations between industry, transport and the environment.

In addition to an introduction and a chapter with conclusions, the thesis has six main chapters. The six chapters consist of a relatively comprehensive theoretical contribution, four articles and a conference paper expanded with a separate set of endnotes. The theoretical chapter is not previously published. Two of the articles are printed, and two are submitted for publishing, in international scientific journals.

The introduction (Ch.1) presents the background for the problem issues in the thesis and the theoretical framework. This includes a classification of transport problems understood as *efficiency-, pattern- or volume problems*. The superior problem issue is:

- How can we understand relations between industrial ecology and transport?

The superior problem issue is addressed through three leading issues that define, in an operational sense, the scope and content of the thesis:

- To what extent are transport problems themes in the various understandings of industrial ecology?
- How are transport problems understood in industrial ecology?
- What is the role of actors in the relations between industrial ecology and transport?

Chapter 2 consists of a review of the main literature contributions to the field of industrial ecology. This is carried out in the form of developing a *typology of different understandings of industrial ecology*. The characterisation and classification of the different understandings of industrial ecology has given basis to identification of transport problems emerging in connected with the concept. Five main types of industrial understandings are identified and characterised. The transport problems connected to the different understandings are illustrated, and characterised according to the three dimensions efficiency, pattern and volume.

The first article (Ch.3) gives an analysis of implications with the use of industrial ecology principles for *rural industry*. The relation between industrial ecology and transport is studied in connection with small and medium sized enterprises (SME). It is shown a.o. that these companies have limited possibilities for taking part in *energy efficient recycling systems* (industrial ecosystems) due to long and energy demanding transport distances between the companies. The article is based on

results from a project in the Ministry of Local Government programme for industry-targeted research.

In the second article (Ch.4) industrial ecology is used as a framework for an analysis of *transport energy*. It is shown what implications the use of transport energy can have for the products. The importance of transport energy in a natural resource based production system is illustrated. By using fish as example, it is shown that the amount of transport being used, to a large extent depends on the method used for transporting the product. In the article the industrial ecology principle of life cycle approach is used for assessing energy use. The analysis therefore includes the transport of the finished product from Norway to the receiving country. In the analysis it is shown that this last part of the transport chain can be extremely energy demanding for the product fish. This has implications for the products, and the state of the product fish (fresh, frozen, dried, smoked) during transport.

The third article (Ch.5) presents *scenarios* for *person transport* in Oslo, as part of a company's environmental strategy. The scenarios developed for the public transport company Oslo Sporveier illustrate the use of industrial ecology as a frame for environmental strategy work. The basis for three different scenarios for development of person transport up to the year 2016 is presented. Analyses are performed of the consequences of person transport, in the form of energy-, land- and time use, together with emissions of CO_2, NO_x and particles, in the scenarios. The three scenarios are: 1) a *private car scenario*, where the growth in person transport is mainly met by an increase in the use of private cars, 2) a *public transport scenario*, where the growth in person transport is mainly met by an increase in the use of public transport, and 3) a *sustainable transport scenario*, with a reduction in total person-mobility, combined with increased share of public transport and walking/bicycle use, and reduced use of private cars.

In the fourth article (Ch.6) a discussion is given of *environmental reporting* in the transport sector. In addition to a general analysis of this theme, empirical material from Oslo Sporveier is used. The relation between transport and industrial ecology is studied through development and implementation of systems for environmental reporting in the transport company. The process of preparing the environmental report for Oslo Sporveier for the year 2000 is analysed, and examples of environmental improvement actions and indicators are given. The article presents in addition results from analyses of the company transport activities, which in addition to the main activity of providing public transport services, also include the employee work- and company travel. The *societal accounting* of the company is presented, and it is shown how this is used in the environmental reporting.

In Chapter 7 the relation between industrial ecology and alternative energy for transport is addressed. This is analysed from an industrial ecology perspective of loop-closing by connecting bus companies to *energy systems based on biological renewable resources*. Implementation strategies for biological renewable energy systems in the transport sector in general are also discussed. Limits and barriers for the use of biodiesel produced from rape/colza (RME) and biologically-based motor-alcohols, are addressed using industrial ecology as framework. This includes identification of national, company-related and motor-technical barriers for RME production and use in Norway. In addition, this article analyses the effect of a transition to RME use, on changes in emission of greenhouse gases. The article also presents the experiences with the use of stakeholder group networks in connection with implementation of biologically based motor-alcohols.

The conclusions chapter (Ch.8) summarises the main contributions of the thesis to understanding relations between transport and industrial ecology. The empirical material from the five chapters 3-7 are connected together with the theoretical contribution (Ch.2). In this way it is shown how both theory and empirical material shed light on the main problem issues of the thesis. This gives basis for some generalisations on problems and prospects connected to industrial ecology in relation to transport.

SAMMENDRAG

Denne avhandling omhandler relasjonene mellom *industriell økologi* og *transport*. Avhandlingen tar opp hvordan *problemer* knyttet til transport forstås innenfor rammen av industriell økologi. Spesielt tar avhandlingen for seg transportproblemer i ulike forståelser av industriell økologi. Det overordnede formålet er å utvikle forståelse for relasjonene mellom transport og industriell økologi. Både teoretisk og empirisk forskningstilnærming og materiale er anvendt. Teoretisk ved å gjennomgå litteratur om fagfeltet industriell økologi, samt karakterisere og kategorisere de sentrale litteraturbidragene. Dette har gitt grunnlag for utvikling av en *typologi* for ulike forståelser av industriell økologi. Empirisk ved analyser av case med basis i resultater fra en rekke *forskningsprosjekter* gjennomført ved Vestlandsforsking gjennom en periode på ca 8 år. De er alle prosjekter med hovedfokus på forholdet mellom industri, transport og miljø.

Ved siden av en innledning og et kapittel med konklusjoner består avhandlingen av seks hovedkapitler. De seks kapitlene består av et relativt omfattende teoribidrag, fire artikler og et konferanse-paper utvidet med et eget sett sluttnoter. Teorikapitlet er ikke tidligere publisert. To av artiklene er publisert, og to er innlevert til publisering, i internasjonale vitenskapelige tidsskrift.

I innledningen (kap.1) presenteres bakgrunnen for avhandlingens problemstillinger og det teoretiske rammeverket for belysning av disse. Dette inkluderer en inndeling av transportproblemer forstått som *effektivitets-, mønster- eller volumproblemer*. Den overordnede problemstilling er:

- Hvordan kan vi forstå relasjonene mellom industriell økologi og transport?

Den overordnede problemstilling er belyst gjennom tre underordnede problemstillinger som definerer, på en operasjonell måte, avhandlingens rammer og innhold:

- I hvilken grad er transportproblemer tema i ulike forståelser av industriell økologi?
- Hvordan forstås transportproblemer i industriell økologi?
- Hva slags rolle har aktører i relasjonene mellom industriell økologi og transport?

Kapittel 2 består av en gjennomgang av de viktigste litteraturbidragene til fagfeltet industriell økologi. Dette er gjort i form av utvikling av en *typologi for ulike forståelser av industriell økologi*. Karakteriseringen og klassifiseringen av de ulike forståelsene av industriell økologi gir grunnlag for identifisering av transport-problemer som reiser seg i tilknytning til begrepet. Fem hovedtyper forståelser av industriell økologi er identifisert og karakterisert. Transportproblemene som knytter seg til de ulike forståelsene er illustrert, samt karakterisert i henhold til de tre dimensjonene effektivitet, mønster og volum.

Den første artikkelen (kap.3) gir en analyse av implikasjoner ved anvendelse av industriell økologi -prinsipper for *distriktslokaliserte industribedrifter*. Relasjonen mellom industriell økologi og transport er studert i tilknytning til små og mellomstore bedrifter (SMB). Det synliggjøres bl.a. at disse bedriftene vanskelig kan ta del i *energieffektive resirkuleringssystemer* (industrielle økosystemer) p.g.a.

lange og energikrevende transportavstander mellom bedriftene. Artikkelen bygger på resultatene fra et prosjekt i Kommunaldepartementets næringsrettede forskningsprogram.

I den andre artikkelen (kap.4) benyttes industriell økologi som et rammeverk for en analyse av *transportenergi.* Det vises hvilke implikasjoner dette kan ha for *produktene*. Betydningen av transportenergi i et naturbasert produksjonssystem er illustrert. Ved å bruke fisk som eksempel vises det at mengden transportenergi som brukes er svært avhengig av måten produktet blir transport på. I artikkelen brukes industriell økologi -prinsippet om livssyklustilnærming for vurdering av energibruk. Analysen inkluderer derfor transporten av det ferdige produktet fra Norge fram til mottaksland. I analysen vises det at denne siste delen av transport-kjeden kan være ekstremt energikrevende for produktet fisk. Dette har implika-sjoner for produktene, og formen av produktet fisk (fersk, frossen, tørket, røkt) under transport.

Den tredje artikkelen (kap.5) presenter *scenarier* for *persontransport* i Oslo, som en del av en bedrifts miljøstrategi. Industriell økologi som en ramme for *miljøstrategisk* arbeid i bedrifter er synliggjort gjennom scenariene utviklet for kollektivtransportselskapet Oslo Sporveier. Grunnlaget for tre ulike scenarier for utvikling av persontransport fram til år 2016 presenteres. Artikkelen tallfester persontransportens konsekvenser i form av energi-, areal- og tidsbruk, samt utslipp av CO_2, NO_x og partikler i scenariene. De tre scenariene er 1) et *personbilscenario*, hvor hovedveksten i persontransport tas hånd om gjennom en økning i personbil-bruken, 2) et *kollektivscenario,* hvor veksten i persontransport tas hånd om av økt bruk av kollektivtransport og 3) et *bærekraftscenario*, med en reduksjon i total personmobilitet, kombinert med en økt andel kollektivtransport og bruk av gange/sykling, og redusert andel privatbilbruk.

I den fjerde artikkelen (kap.6) gis det en diskusjon av *miljørapportering* innen området transport. I tillegg til en generell analyse av dette temaet, benyttes empirisk materiale fra Oslo Sporveier. Relasjonene mellom transport og industriell økologi er her studert gjennom utvikling og implementering av systemer for miljø-rapportering i en transportbedrift. Prosessen med å lage miljørapporten for år 2000 for Oslo Sporveier analyseres, og det gis eksempler på miljøforbedringshandlinger og indikatorer. Artikkelen presenterer også resultater fra analyser av bedriftens transportaktiviteter, som i tillegg til hovedaktiviteten kollektivtransportdrift, omfatter de ansattes arbeids- og forretningsreiser. Bedriftens *samfunnsregnskap* presenteres, og det vises hvordan dette benyttes i miljørapporteringen.

Kapittel 7 tar opp relasjonen mellom industriell økologi og alternativ transport-energi. Dette er analysert fra et industriell økologi perspektiv om kretsløps-lukking ved busselskapers tilknytning til *energisystemer basert på biologiske fornybare ressurser*. I tillegg diskuteres implementeringsstrategier for biologiske fornybare energisystemer i transportsektoren generelt. Begrensninger og barrierer for bruk av biodiesel fra raps/rybs (RME) og biologisk-baserte motoralkoholer, er diskutert ut fra industriell økologi -perspektiver. Både nasjonale, bedriftsmessige og motortekniske barrierer for RME -produksjon og -bruk i Norge er analysert. I tillegg beregnes effekten av en overgang til RME bruk, i form av endringer i utslipp av klimagasser. Artikkelen presenterer også erfaringene med bruken av interessentnettverk i forbindelse med implementering av biologisk-baserte motoralkoholer.

I konklusjonskapitlet (kap.8) oppsummeres avhandlingens bidrag til økt forståelse for sammenhengen mellom transport og industriell økologi. Det empiriske materialet fra kapitlene 3-7 knyttes sammen med det teoretiske bidraget (kap.2). I denne sammenfatningen vises det hvordan både teori og empiri belyser avhandlingens sentrale problemstillinger. Dette gir grunnlag for noen generaliseringer omkring industriell økologi og transport.

LIST OF ABBREVIATIONS

ALTENER	European Commission DG-XVII programme for increased use of renewable energy
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CCFPP	Critical cold filling (or filter) pouring (or plugging) point
CEM	Corporate environmental management
CFC	Chlorofluorocarbon
CF_4	Carbon tetra fluoride
C_2F_6	Hexafluoroethane
CMA	United States Chemical Manufacturers Association
CO	Carbon monoxide
CO_2	Carbon dioxide
CSR	Corporate social responsibility
DFE	Design for environment
EMAS	Eco-management and auditing scheme
EMS	Environmental management system
EPA	United States Environmental Protection Agency
FAME	Fatty acid methyl ester
GMO	Genetically modified organism
GNP	Gross national product
GWh	Giga watt-hours
ha	Hectare
HC	Hydrocarbon gases
HF	Hydrofluoric acid
HFC-134a	Tetrafluoroethane
HSE	Health, safety and environment
LCA	Life cycle assessment / Life cycle analysis
MIPS	Material input per service unit
3M	Minnesota Mining and Manufacturing Corporation
NGO	Non-governmental organisation
N_2O	Nitrous oxide
NO_x	Nitrogen oxides
NOK	Norwegian krone
pkm	Person-kilometre
PPD	Pour point depressor
PPM	Parts per million
PM_{10}	Particulate matter with aerodynamic diameter <10 micrometer
$PM_{2.5}$	Particulate matter with aerodynamic diameter <2.5 micrometer
RME	Rape methyl ester
SAVE	European Commission DG-XVII programme for increased energy efficiency
SL	Greater Oslo Local Traffic
SME	Small and medium sized enterprise
SO_2	Sulphur dioxide
TMR	Total material requirement
VOC	Volatile organic compounds
VR	Virtual reality
VTT	Technical Research Centre of Finland

1. Introduction

The title of this thesis is "Transport and Industrial Ecology – Problems and Prospects". This title implies that *transport* and *industrial ecology* are the two main themes addressed, and particularly the relations between them. These relations cause *problems*. But there are also *prospects* about the way they may be handled. Industrial ecology is fundamentally about how environmental problems may be solved or limited. Industrial systems necessarily involve transport. The focus on transport in relation to industrial ecology has its background in the serious environmental problems caused by transport.

1.1. Environmental problems of transport

The following seven points illustrate the environmental problems connected to transport[1]:

- The transport sector is the source of *an unusual wide range of environmental impacts*. They cover a range from global to local effects, from consequences for the natural environment to health effects, from impacts on cultural landscape to destruction of cultural monuments and valuable built environments.

- The transport sector is responsible for a large part of the *global consumption of energy and material resources*. In the rich industrial countries, more than 30% of the total energy consumption is on the whole linked to transport. The high energy consumption does not only constitute a problem of global character, it is also in itself the source of environmental impacts where the resources are consumed in terms of exploitation, production, and transportation. The *transportation* of the transport means and the fuels is one of the major global streams of goods transport.

- Transport is an important source of many of the serious environmental and health impacts caused by *the emission of polluting substances*, especially to air. These are emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), particulate matter (PM), sulphur dioxide (SO_2), etc. Several of the emission substances are also important in the formation of tropospheric ozone, which in turn is a source of health effects, impaired plant growth, and degradation of biological diversity. Noise can also be understood as a type of emission to air. In this respect transport is a dominating source in cities and urban areas, as well as connected to important transport elsewhere.

- The transport sector is special in the way that it is close to 100% *based on fossil energy*, that is, the energy resource that many of the most serious environmental impacts are linked to. Globally, fossil oil products account for 98% of all energy consumption for transport purposes. This represents more than 60% of the consumption of all fossil oil products in the world, but

[1] The description of environmental problems from transport through the list of seven points is based on Høyer (2000).

obviously a smaller share of *all* fossil energy (which also includes natural gas and coal). Road transport is almost completely based on fossil oil, and it dominates in terms of volume as well. In the OECD countries road transport on average makes up 80% of all fossil oil used for transport. Most of the remaining 20% is used for air transport, whereas rail and boat just account for approximately 5% (OECD, 1996).

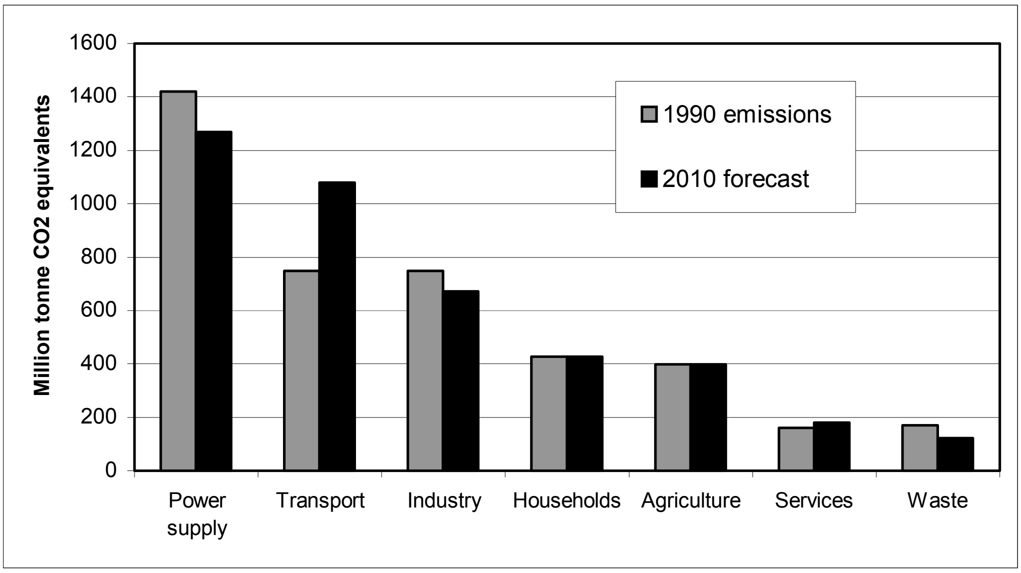
- The development of the infrastructure of transport, coupled by the barriers caused by its use, are – as elements of an increasingly more extensive and finely-meshed network – important sources of the *degradation of biological diversity* and other values linked to the characteristics and localisation of land. The latter refers, for example, to the deterioration of cultural landscapes and production values for human activities, such as *agriculture*.

- The infrastructure of transport, but also the polluting emissions from the use of the transport means, is an important, perhaps *the* most important source of the deterioration of cultural monuments and valuable built environments. This applies particularly to cities and urban areas. In this context it has been suggested that the transport sector in the past few decades can be blamed for more destruction of such cultural values in western European cities than the total of all bombing during World War II (Høyer & Simonsen, 1996). In strongly car-based cities and urban areas, the transport land areas may occupy as much as 30-40% of the total land.

- In all OECD countries, the transport sector is the main source of the special accumulation of serious environmental impacts we get in the largest cities and urban areas. This is particularly the case with environmental impacts that affect the *health*. According to the recommended limits by the Norwegian Pollution Control Authority (SFT), 600 000-700 000 people in Norway are living in areas with too high concentration of NO_2 and particles. The critical concentration of ozone – with regard to plants as well as to human health – is exceeded practically all over the country. Road traffic alone leads to an excess of recommended limits for outdoor noise in residential areas for about 1.35 million people. In addition, of all the society's economic sectors, transport accounts for the major share of fatal accidents and accidents causing injuries to people.

There is in addition one aspect of the environmental problems of transport that make them particularly important; many of them are increasing rapidly in magnitude. One example is the greenhouse gas emissions from transport. While the greenhouse gas emissions from power generation, industry, households, agriculture, services and waste in the European Union are expected to remain approximately stable or be reduced towards the year 2010, the emissions from transport are expected to rise substantially (*Figure 1*).

Figure 1 *Contribution of key sectors to greenhouse gas emissions in the EU. 1990 emissions and 2010 forecast*



Source: EC (2001)

The expected increase in transport's contribution to major environmental problems in the future is the main reason for the key focus on transport in this thesis. Another reason is that transport is rather important in the debate connected to sustainable development, particularly connected to modern industrial societies. In the main chapter on energy in the Brundtland Commission report "Our Common Future", transport is an important source of three of the four environmental problems the commission highlights as implied in a future consumption of energy (WCED, 1987, p. 129). These are:

- The risk of climate changes due to increased emission of CO_2 from the combustion of fossil fuels
- Air pollution in cities and industrial areas caused by the combustion of fossil fuels
- Acidification of the environment for the same reason

1.2. Different ways of understanding transport problems

As indicated in the previous chapter, the problems connected to transport are many and complex. One way of differentiating transport problems is that they range from *technical* to *systemic* problems, requiring successively greater changes to society. Another, but related differentiation is to use the dimensional axis *efficiency-pattern-volume* (*Figure* 2). This way of differentiating transport problems is found more suitable for the application in this thesis. It is based on previous work by researchers at Western Norway Research Institute (Høyer et al., 1998; Høyer, 2000). The problems on this axis range from relatively simple problems connected to the efficiency of transport (*efficiency)*, to successively more complex problems of societal systemic character (*volume*). In addition to these two main dimensions, the axis has an intermediate position (*pattern*). At each endpoint the most extreme variants of *efficiency* and *volume* are found.

Intermediate positions between the three main dimensions also exist. A certain transport problem can for example be characterised as both having characteristics of *pattern* and *volume*. We can also speak of a transport problem having both pattern and volume *effects*[2].

Figure 2 *The efficiency-pattern-volume dimensional axis*

Efficiency problems

- *How to improve aerodynamics of vehicles*
- *How to purify exhaust emissions*
- *How to recycle vehicles and infrastructure*
- *How to make fuel efficient engines*
- *How to use more renewable energy sources*
- *How to increase capacity utilisation (load factor)*

Pattern problems

- *How to make substitutions between means*
    - *Bus instead of car?*
- *How to make substitutions between modes*
    - *Goods transport: Water and rail instead of road and air?*
    - *Person transport: Rail instead of road?*
- *How to make substitutions between non-motorised transport (walk/bike) and motorised transport*

Volume problems

- *What societal and individual processes can reduce transport?*
    - *How can infrastructure and land use planning reduce transport?*
    - *How can locating functions for improving accessibility reduce transport?*
    - *How can global mobility of goods and people be reduced?*

The efficiency problems of transport are connected to the aim of making improvements in existing transport, or processes of doing things better. This includes technical problems connected to improving the environmental performance of existing transport and creating new and more efficient transport means. This is an important aspect of industrial ecology. Design with the aim of reducing the wind resistance (aerodynamic design) of automobiles is on the extreme side of the efficiency end of the dimensional axis. An approach to "solving" the main transport problems by building cars with improved aerodynamic design can thus be considered as an extreme variant of the efficiency

[2] Both positive and negative effects are possible. In general, the transport problems are considered as having negative effects. Hovewer, if one focuses on prospects or solutions, it is also possible to concieve of positive effects of various approaches to deal with the transport problems. This implies that the efficiency-pattern-volume dimensional axis, in addition to differing between transport *problems*, also can be understood to differ between various *approaches* to find *solutions* to transport problems.

understanding. Reducing emissions by various purification technologies, such as through the installation of catalytic converters, filters and particle traps are also examples of efficiency approaches, but less extreme than the approach of obtaining aerodynamic design. Another efficiency problem is how to improve the recyclability of transport means. This include problems connected to material choice for improved material recyclability and re-use of parts. The production of more fuel-efficient engines is another example of a less extreme variant of efficiency approaches. Other transport approaches on the efficiency segment, but less extreme, include the transition to more use of renewable energy sources, and the improvements in capacity utilisation by increasing load factor in goods transport and occupancy rate in person transport.

Pattern-problems of transport can be understood as being caused by the relative usage of different transport forms. Changes to transport patterns are obtained by changes in the relative usage share of the various means and modes of transport[3]. This includes the substitution of transport modes and means with environmentally preferred alternatives. Transport on water and rail instead of road and air are key mode substitutions for goods transport. These mode-substitutions can occur by changes away from lorry and aeroplane use to more use of railways, cargo ships at sea and barges on inland waterways. Mode substitution in goods transport can imply major savings in energy use. Lorry-based transport is much less energy efficient than rail and water-based transport. The average lorry transport in Finland, for example, requires a factor of 6 times more energy per tonne transported goods, compared with rail transport, and about 3 times more than transport on water (Andersen et al., 2001). The corresponding factor for lorry transport in Norway are about 4 times higher than rail and 5 times higher than water-based transport (ibid.).

Using bus instead of car is an example of a transport mean substitution for person transport using the road-based transport mode. The other main substitution in motorised person transport is change from private car and aeroplane to more use of rail-based transport. These substitutions can imply major savings in energy use. On the average public transport is much more energy efficient than transport by car. A study of person transport in Oslo indicates a 35% lower energy use per pkm for bus than car (Andersen, 2001). A 74% reduction in energy use can be obtained by changing from automobile usage to rail (metro).

Changes in transport pattern can also occur through substitution of motorised transport with the more environmentally preferable non-motorised transport (walking and bicycling). This can occur either as a change of transport mean or a change of transport mode. An example of the former is change from the use of car or bus to the use of non-motorised bicycle or walking. The change from tram or metro to more use of non-motorised bicycle or walking is an example of the latter.

Also within the main dimension pattern, the order of placement on the axis is far from random. The pattern issues that share characteristics with efficiency issues are positioned close to the efficiency dimension. Correspondingly, pattern issues

[3] A distinction is made between transport *mean* and transport *mode*. Transport *modes* are: road, water (sea and inland waterways), air and rail. Transport *means* are vehicles, ships, airplanes and rains. Vehicles are road-based transport means, such as automobiles, buses and lorries.

that also share characteristics with volume problems are positioned close to the volume dimension. Changes in transport means can in general be considered closer to the efficiency dimension than the case is for changes in transport modes. How to obtain changes from motorised transport to non-motorised transport (walking and bicycling) is however the pattern problem that is considered to have the most connection to volume problems.

V*olume* problems of transport are of particular interest today, as these forms of environmental problems are rapidly increasing in importance. It is the sum of all the individual automobiles, aeroplanes, and lorries etc., which contribute most to the major environmental problems, such as climate changes due to the emission of greenhouse gases. These problems are connected to lifestyle changes and the *systemic* character of society, in contrast to the efficiency problems, which are less complex and mainly connected to technical aspects. The volume problems are strongly connected to the necessity of making reductions. The focus is on societal and individual processes for reducing motorised transport of both people and goods. This includes establishing of industrial infrastructure and land use practices that minimise the need for motorised transport. Locating societal functions for improving accessibility can also reduce the need for transport. A reduction in the global mobility of both people and goods is one of the most comprehensive issues connected to the volume segment of the efficiency-pattern-volume dimensional axis.

In the industrial ecology literature the transport problems have been divided according to a similar 3-level differentiation. In connection with the development of urban transport systems Thomas Graedel et al. (2002) identify three general problem approaches, requiring successively greater changes in lifestyle and infrastructure:

1. Improve private transport through advances in car and road design
2. Establish public transport systems that meet or exceeds the expectations of current car users
3. Minimise the need for transport through more use of telecommunication, and locating services within walking or biking distance of residents.

The three approaches presented by Graedel (ibid.) thus resemble the efficiency-pattern-volume dimensional axis in *Figure 2*. The first approach, focusing on improvements in current transport, corresponds to the efficiency-segment. The second approach is about making public transport more attractive, facilitating a transport pattern change. The third approach is about minimising the need for transport, with the potential for subsequently reducing transport volumes.

The *efficiency-pattern-volume* dimensions transport problems can also be considered having a parallel in the field of *ecological economy.* In the discussion of social conditions for achieving sustainable development, the American economist Herman E. Daly uses *allocation*, *distribution* and *scale* as determinants of environmental degradation (Daly, 1992; Daly & Foy, 1989; Daly & Foy, 1992). It might appear, at first glance, that there are two quite different themes being considered. However, considering Daly's 3 dimensions might help comprehending the division of transport problems into efficiency, pattern and volume problems. Daly explains the three issues allocation, distribution and scale as follows:

- *Allocation* refers to the distribution of the throughput of natural resources to different end-use applications. Thus, it refers to how much of the resources that are used to private cars, houses, clothing, water and sanitary purposes etc.
- *Distribution* refers to the distribution between people, of the throughput of natural resources in the form of end-use products and services. Thus it refers to how much of the resources that are distributed to you and me, to people in other regions of the world, and to people in future generations.
- *Scale* refers to the total volume of the throughput of natural resources and waste- and emission-products. Thus, it refers to the volumes of sources and sinks.

According to Daly acceptable volumes (scale) must be decided *before* distribution and allocation. At the same time these volumes must be determined through political decisions, and the decisions must reflect physically defined ecological limits. The next step is to decide on distribution through criteria of distributional justice. This is also a matter of political decisions. Only after having politically determined the ecologically acceptable volumes and the ethically just distribution, can allocation take place through market economy. Intervening in scale (volume) and distribution (pattern) can thus only be done at a superior societal or political level. It is only for the allocation (efficiency) issue that the market forces can play a role. A similar reasoning can be made for transport problems, in that the volume and pattern problems require comprehensive and for the most part policy-driven approaches, while efficiency problems are more suitable for being controlled by the market forces.

1.3. Industrial ecology

Industrial ecology aims at reducing the environmental impacts of industrial activities. It is a relatively broad concept which includes materials, processes, products and facilities. It also covers how these components of the industrial systems are linked together through flows of material resources, as well as the interaction with natural ecosystems. Since industrial ecology is a system-based approach, it is in principle, applicable for dealing with environmental problems caused by transportation systems.

The concept industrial ecology has roots back to the 1950's from a concern of potential limits of raw materials, caused by an increasing demand for resources. The possible depletion of the world's stock of minerals was a result of economic growth and expansion of mineral extraction in connection with the rebuilding of war-torn nations after 1945 (Hodges, 1995).

Many of the core ideas of industrial ecology, such as material flow analysis, have been practiced since the 1960's most notably by Robert Ayres (Ayres and Kneese, 1969; Ayres and Nair, 1984; Ayres et al., 1985). This area would later be termed *industrial metabolism* (Ayres, 1989). In a special issue of Scientific American on "Managing planet earth", the core principles of industrial ecology were introduced to the scientific literature at large (Frosch and Gallopoulos, 1989). The notion of *industrial ecosystems*, using the ecosystems in nature as models for the organisation of industrial activity, was launched:

> "Wastes from one industrial process can serve as the raw material for another, thereby reducing the impact of industry on the environment"
> (Frosch and Gallopoulos, 1989, p. 94)

This time the concept sparked off a considerable interest, primarily by industry and academia, and later also by governing bodies. Subsequently, a large number of scientific contributions in the field of industrial ecology appeared, in the form of journal articles, conference papers and books (Ausubel and Sladovich, 1989; Frosch, 1992; Tibbs, 1992; Socolow et al., 1994; Ehrenfeld, 1994; Allenby and Richards, 1994; Frosch, 1995; Graedel and Allenby, 1995; O'Rourke et al., 1996; Ayres and Ayres, 1996; Lowe et al., 1997; Allenby, 1999; Ayres and Ayres, 2002). These contributions represent *different understandings* of the concept industrial ecology. This literature is reviewed and the various understandings characterised in Chapter 2 – An Industrial Ecology Typology.

1.4. The handling of environmental problems of transport in industrial ecology

Since industrial ecology is emerging as a framework for industry, it becomes relevant to ask the question of how problems of transport are handled within this field. Dara O'Rourke et al. (1996), in a critical review of industrial ecology, point to the lack of considerations regarding energy use in general as a main weakness in the industrial ecology literature. When transport problems are focused in industrial ecology, they mainly deal with technical aspects of designing less environmentally harmful motor vehicles. When applying design for environment[4] (DFE) in industrial ecology, O'Rourke et al. (ibid.) point to the danger that larger questions regarding the sustainability of transportation systems largely dependent on petrol powered automobiles are not addressed. Instead, these questions are being buried under complicated, but relatively unimportant technical design problems (e.g. plastic versus aluminium car components).

Global transport of goods is analysed, from the perspective of industrial ecology, by Stephen Bunker (1996). He points to examples of false claims of dematerialisation[5] in the industrial ecology literature. By not accounting for the

[4] Design for environment is a term commonly used in connection with industrial ecology. It implies that products should be designed to minimise the environmental impacts during the use phase, and to make possible easy disassembly and re-use after the end of use.

[5] Dematerialisation is often used as a term for resource efficiency, or the more efficient use of available resources. A more up-coming definition of dematerialisation takes into consideration the change from product to services. This concerns the reduction in material input per service unit (MIPS), which refers to the mass of materials needed to produce one unit of a service. An even more comprehensive definition, from an ecological point of view, is:

> "Dematerialisation is the decline in the total global amount of resources (i.e. material and energy) mobilized to manufacture one unit of an industrial product/service, without changes in the basic qualities of the product/service".
> (Høyer, 2000, p. 82)

strong increase in volumes of global transport of goods, which has occurred the last decades, claims of global dematerialisation cannot be made.

Several other industrial ecology contributions deal with a limited, but important component of transport; the automotive system (Keoleian et al., 1997; Graedel & Allenby, 1998; Graedel et al., 2002). All these contributions use a life-cycle perspective on the analysis of the design of the automobile product. They also include analyses of material usage, including considerations of materials for use in infrastructure. Compared to analysis of material use, energy use issues are however given little attention.

The examples above indicate that some important transport questions are dealt with in the discussion connected to industrial ecology. Both simple and more complex transport problems in connection with the concept industrial ecology can be found in the international literature. Bunker (1996) applies a more complex perspective, focusing on fundamental transport problems, exemplified by the increase in global transport volumes.

Initially when considering the concept industrial ecology, it might however appear that transport either is not included, or is only included to a limited extent in various interpretations and understandings of the concept.

1.5. Problem formulation

Transport is a major source of the local, regional and global environmental problems. Industrial ecology aims at reducing the negative environmental consequences of industrial activities. It thus becomes important to understand the relations between industrial ecology and transport. It is a main problem for assessing industrial ecology's prospects for handling the environmental problems connected to transport that these relations are not well understood. This Ph.D. thesis therefore aims at improving this area of understanding – the relations between industrial ecology and transport. The *superior issue* of the thesis is therefore:

- How can we understand relations between industrial ecology and transport?

The term *understand* implies that the focus in the thesis is not on explaining, but rather at obtaining increased knowledge of the relations between industrial ecology and transport. The focus is on various ways the concept of industrial ecology is understood and applied, with a particular attention to the environmental *problems* connected to transport and transport systems. A relatively broad approach to industrial ecology is chosen, to throw an extensive light on transport relations in industrial ecology.

Since transport is an increasingly important contributor to many of the most serious environmental problems connected to industrial societies, it is important to understand how transport is handled within the frame of industrial ecology. This is addressed through two *leading issues* that define, in an operational sense, the scope and content of the thesis:

- To what extent are transport problems themes in the various understandings of industrial ecology?
- How are transport problems understood in industrial ecology?

Since industrial ecology aims at reducing the environmental impacts of industrial activities, the element of *change* becomes important. Improvements in industrial systems occur through making changes. Industrial ecology is thus to a large extent connected to the act of making changes to industrial systems. Changes, such as the implementation of industrial ecology principles, occur through the involvement of individual *actors* or *actor groups*. It is therefore important to identify the role of actors, in various understandings of industrial ecology. A third leading issue can thus be formulated:

- What is the role of actors in the relations between industrial ecology and transport?

1.6. Methodological approach

1.6.1. Overall methodological approach

In this thesis a case-methodology is applied for the purpose of making generalisations on relations between industrial ecology and transport. An understanding of generalisation from case studies similar to the understanding of Robert K. Yin (1994) is applied. Yin differentiates between *statistical* and *analytical* generalisation, and makes the point that the case-methodology to a larger extent is based on analytical generalisation. Analytical generalisation is based on logical sequence of reasoning with emphasis on theoretical considerations, while in statistical generalisation much emphasis is on statistical techniques with stringent criteria regarding selection of study units.

Several research projects form the basis for the cases in this thesis. In the research projects, as well as in the thesis, mainly analytical, rather than statistical generalisations are applied.

A specific understanding of the term ”case” is used in the thesis. The term is expressing, as in Yin (ibid.), the empirical and theoretical sources for generating knowledge. The empirical cases are presented in the thesis in the form of four articles (Chapters 3-6) and one conference paper expanded with additional notes (Chapter 7). For the purpose of simplicity, the five empirical contributions are all referred to as ”articles”.

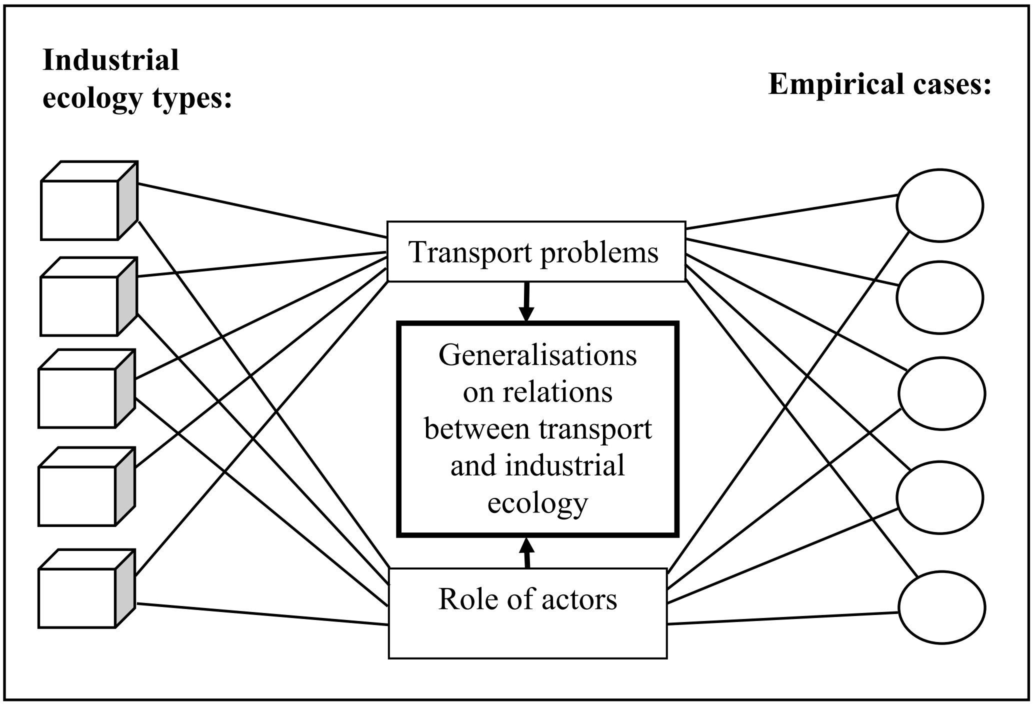
The research projects forming the basis for the five cases have not specifically been designed to elucidate the relations between industrial ecology and transport. They are first of all projects about transport problems. But the transport problems are studied in connection with industrial systems. They thus provide knowledge relevant for understanding relations between industrial ecology and transport. In addition they study a wide range of transport problems. The research projects forming the bases for the cases are thus well suited to provide knowledge about transport - industrial ecology relations because they:

- Study transport in industrial systems
- Study a wide range of transport problems

In addition to the empirical material in the form of the cases there is in the thesis also a main theoretical contribution. It consists of a typology (Chapter 2) where five different industrial ecology understandings drawn from international literature are identified. These five theoretical industrial ecology types handle transport differently, both in terms of the actual transport problems addressed, and the limits and potentials. The typology is mainly descriptive, based on central contributions found in the industrial ecology literature. In total, the five types of understandings can be considered to represent a description of the field of industrial ecology.

From the empirical cases and the theoretical contribution, some analytical generalisations are made. This is illustrated in *Figure 3.*

Figure 3 *The basis for generalisation from cases and theory*



In *Figure 3* the five cubes to the left represent the five industrial ecology types (understandings) drawn from the international literature. The types have different potentials for handling transport problems. For each of the five types it is described how and which transport problems are addressed. This is shown in *Figure 3* by the line from each cube to the rectangular box labelled "Transport problems". Four of the industrial ecology types are tightly connected to changes, and thus also the role of actors. For these four types the role of actors is described, shown by the lines from four of the cubes to the rectangular box labelled "Role of actors".

The empirical cases are shown as ellipses in *Figure* 3. The lines from each ellipse to the “Transport problems”- rectangular box illustrate that the transport problems in each case are described.

The cases have different characteristics, which makes it possible to connect them to one or several industrial ecology types. Each case can thus be considered to represent the application of one or several industrial ecology understandings. It is expected that transport problems are addressed in certain ways, based on what type(s) that each case is connected to. The cases then illustrate how transport problems emerge, and this is discussed in relation to what can be expected from the industrial ecology types. A similar logic is applied for the role of actors. Four of the empirical cases represent the application of industrial ecology types with a strong connection to change, and for these cases there is also a description of the role of actors. This shown in *Figure 3* by the lines from four of the ellipses to the “Role of actors” – rectangular box.

In summary, the empirical (cases) and theoretical sources (industrial ecology typology) of material are basis for analysing transport problems and role of actors in industrial ecology. This is used for making general conclusions on problems and prospects of transport in connection with industrial ecology.

1.6.2. The basis in research projects

This thesis is based on theoretical and empirical material from several research projects carried out at Western Norway Research Institute. They are all projects with a prime focus on relations between industry, transport and the environment. In most of the projects I have had the function as project leader in combination with active researcher. This implies that several researchers have contributed to the research material that forms the basis.

The detailed methodological approach in each empirical case is described in the five articles constituting the case-presentations. What follows is a brief description of each research project and their main method approach.

1995-1997. Green-SMEs. This was a project under Norwegian State Department of Local Government. The relation between industrial ecology and transport was studied for small and medium sized enterprises (SMEs). The main aim was to develop knowledge of the most important changes SMEs are facing in terms of future environmental challenges. The main method approach was case-based with 10 individual enterprises as cases. Important actors in the project were the individual SMEs, and their employees. The company facilities, infrastructure, and other framework for the activities of the companies, were also focused. The empirical data material was obtained through series of structural interviews with the employees of the 10 participating SMEs. The interviews were complemented with participatory dialogue with the enterprises where improvement possibilities were discussed. In two of the case companies, technical environmental audits were carried out. These audits consisted of detailed mapping of energy- and material usage of the company activities. Focus was on technical improvements that in addition to have environmental benefits also would imply cost savings, and in that sense the method was inspired by the pollution prevention pays (3P) strategy of 3M in improving the industrial metabolism. For the main part of the case companies the focus was on external challenges, which included customer and supplier demands, pressure from environmental groups, government regulations, banks and the insurance industries.

1996-1998. Transport scenarios for Oslo. The main aim of this project was to provide the basis for environmental reporting for the case company Oslo Sporveier. This comprised of, as part of the company strategy, the developing of scenarios for person transport in Oslo up to year 2016. Relations between industrial ecology and transport were studied through the process of strategic planning in urban transport systems. Energy use, land use, time use and emissions of CO_2, NO_x, PM_{10} and $PM_{2.5}$ connected with person transport in 1996 and in three different scenarios for 2016 were determined. The scenarios were: 1) a private car scenario, where the main growth in total person transport is to be met with a strong increase in the use of private cars, 2) a public transport scenario, where the increase in total person transport is to be met with a strong increase in the public transport, and 3) the sustainability scenario, with a reduction in total person transport, increased share of public transport and walking/bicycling, and reduced share of private car use. The design of the project, as well as the data generation-, and implementation phases were carried out with a close interaction between the researchers and the case company Oslo Sporveier.

1996-1998. Biodiesel in heavy duty vehicles in Norway – Strategic plan and vehicle fleet experiments. This was a project under the European Commission DGXVII ALTENER -programme. The project focused on relations between transport and industrial ecology from the perspective of bus companies' connections to biological renewable energy systems. This coupling between transport companies and a cyclic energy resource system constituted the key connection to industrial ecology for this industrial sector (the transport sector). The main objective of the project was to develop a strategic plan for deployment of biodiesel in heavy-duty vehicles, applicable both for Norwegian Federation of Transport Companies and bus companies. The identification of the main barriers to the use of biodiesel produced from rapeseed in Norway was also an aim. The main methodological approach consisted of identification of barriers to biodiesel at the three different levels: 1) National policies and strategies, 2) Bus companies and 3) Production of rapeseed as raw material for biodiesel. A wide range of national actors was interviewed regarding their opinion of alternative fuels in general and biodiesel in particular. For the identification of barriers in bus companies, actors at the three different levels management, garage / maintenance and drivers in the two participating bus companies were interviewed. This was carried out before, during and after fleet tests with biodiesel driving in the buses. The fleet tests also gave empirical basis to the strategic plan for implementation of biodiesel in Norway. Particular focus was to identify barriers connected to using biodiesel in cold weather. A literature study of fuel additives and an analysis of barriers connected to the production of rapeseed as raw material for biodiesel. For the identification of barriers connected to the production of biodiesel a life-cycle approach to the fuel was applied. This included identification of the barriers and limits to cultivation of rapeseed in Norway for three future scenarios of agricultural systems. Biodiesel's potential for reducing the emission of greenhouse gases was also assessed, by including new estimates of nitrous oxide emissions in rapeseed production.

1997-2000. Energy saving in transport of goods – a pilot project in rural natural resource-based industries. This was a project under the European Commission DGXVII SAVE-programme. In the project the relations between industrial ecology and transport were studied in terms of energy efficiency improvements in transport of goods. Within the framework of industrial ecology, energy efficient industrial production systems are important components. The main objective of the project was to gain knowledge of possible actions, strategies and measures for improved energy efficiency in transport of goods in rural, natural resource-based industries in the Nordic countries. The project had three main phases. In the first phase the energy use in transport of goods in the three Nordic countries Finland, Sweden and Norway was analysed. This comprised the compilation of statistical data on the trends in energy efficiency of goods transport by road, rail, sea and air. The second phase of the project comprised of pilot actions for improvement in energy efficiency of goods transport. This engaged actors in the form of a total of four case companies in Finland, Sweden and Norway. The researchers and the participating transport companies interacted through series of interviews and meetings and constructive dialogue. The identification of potentials for improvements of energy efficiency included both analysis of conditions and the implementation of actions through actors connected to the four case companies. The third phase of the project identified measures and actions in regional policies, for improvements in energy efficiency of goods transport. Actors important for mode change from road to rail and sea were identified and subjected to two rounds of structured interviews. Most of these actors were from within the regional and local political/administrative system and transport companies.

1999-2000. Motor-alcohols from wood resources in heavy duty vehicles. A Nordic project on market-penetration through stakeholder group networks. This was a project under the European Commission DGXVII ALTENER-programme. Industrial ecology – transport relations were studied in the form of implementation of strategies for biological renewable energy systems in the transport sector. The role of actors in implementing changes to industrial systems was studied through stakeholder group networks on wood-based motor-alcohols. The main aim of the project was to identify and analyse the most important barriers in the production, distribution and usage of wood-based motor-alcohols in the three Nordic countries Norway, Sweden and Finland. The methodological approach included the forming of stakeholder group networks for wood-based motor-alcohols. These networks consisted of a wide range of actors important for the implementation of wood-based motor-alcohols. They included actors from transport companies, transport organisations, wood-processing industries and manufacturers of wood-based alcohols, distributors of motor-fuels and manufacturers of heavy duty vehicles dedicated to motor-alcohols. The stakeholder group networks are forms of environmental co-operative regimes, which function to successfully manage environmental problems. The project gained experience with the functioning of such regimes, in the area of alternative energies, where they not previously had been tried. The three different study units in the project were 1) the networks themselves, 2) the barriers to the implementation of wood-based motor-alcohols and 3) the required conditions for resolvement of the barriers. The method for resolving the barriers comprised of, through the stakeholder group network, the establishing of co-operative channels to major governing bodies. Through the project new cooperative channels were established, in a setting encompassing three different countries.

2000-2002. Environmental reporting for Oslo Sporveier. The public transport company Oslo Sporveier financed this project. The relations between industrial ecology and transport were studied through the development and implementation of an environmental reporting system for a public transport company. As a basis for the publishing of the first environmental report, basic analyses of energy usage and transport activities in the company were performed. These analyses comprised the energy usage and emissions connected to the basic transport services by tram, metro and bus. The company buildings and properties were also included in the analysis, as well as the company business travels to conferences/meetings and daily employee work travel to and from work. The analysis provided a foundation for identifying company actions for environmental improvements, and indicators for measuring progress. Societal accounting was used to analyse how the environmental effects of the company's services compare with other transport in Oslo. The project design-, data generation-, and implementation phases were all characterised by close interaction between the researchers and the employees of the case company. A wide range of actors within the company organisation was involved, either through the process of gathering relevant data for the reporting, or in the implementation of actions and measures for improving the environmental performance of the company.

1.7. The chapters

In addition to this introduction and the conclusion chapter the thesis consists of 6 main chapters.

The first chapter is:

1. Typology of Industrial Ecology Understandings.
   The chapter is previously unpublished.

The chapter identifies different understandings of the concept industrial ecology, and establishes a typology where the understandings are classified according to their main characteristics. It thus constitutes a theoretical contribution to the field of industrial ecology. The chapter also represents a review of the main literature contributions to industrial ecology. The typology established in the chapter is intended to function as a basis for elucidation of problems connected to transport. The characterisation of the various understandings of industrial ecology facilitates the identification of transport problems emerging with the concept industrial ecology. The chapter identifies a total of five main understandings of industrial ecology, and illustrates the transport themes connected to each individual type.

The four chapters that follow after the typology-chapter are all separate articles published, or submitted for publishing, in scientific journals. They are exactly in the form they have been published / submitted for publishing.

The journal articles are:

2. Industrial Ecology and some Implications for Rural SMEs.
   The article is published in the international journal “Business Strategy and the Environment”, 1997, vol. 6, no. 1, p. 1-7.

The article gives an introduction to industrial ecology and provides an analysis of the implications of applying industrial ecology principles to rural industries. The relation between industrial ecology and transport is through this article studied in connection with small and medium sized enterprises (SMEs). Actual industrial cases and examples of illustrative problems are given. The cases presented are from participating firms in the “Green SMEs” research project. In the article it is shown that the problems include the inability to participate in efficient industrial ecosystems (industrial webs, eco-parks) with exchange of wastes into useable input materials. It is further shown that the ‘cluster’ properties of efficient industrial ecosystems can be a limiting factor in the development of such systems in rural areas. The long transport distances are key barriers in the establishing of industrial ecosystems for small rural industries.

3. Transport of Fish from Norway: Energy Analysis using Industrial Ecology as Framework.
   The article is published in the international journal “Journal of Cleaner Production”, 2002, vol. 10, no.6, p. 581-588.

The article uses industrial ecology as a framework for analysing transport energy and its implication for products. The relations between industrial ecology and transport are studied in terms of energy use in transport of goods. The importance of the energy use for transport in a natural resource production system is analysed in detail. By using fish as case, it is in the article shown that the amount of energy for transport is highly dependent on the transport mode used. The article applies industrial ecology principles for making assessments of the environmental impacts of products, i.e. the whole product chain is examined. This is an extended life-cycle approach, which also includes the transport of the finished products from the exporter to the importing country. The article shows that this last part of the transport chain can be extremely energy demanding in the case of fish transport. This finding has implications for the products and the form (e.g. fresh, frozen, and dried) the products are transported in.

4. Transport Scenarios in a Company Strategy.
   The article is accepted for publication in the international journal “Business Strategy and the Environment”.

The article presents the case transport company Oslo Sporveier’s strategy that includes scenarios for the development of person transport in Oslo up to year 2016. The basis for the scenarios is described. Energy use, area use, time use and emissions of CO_2, NO_x, PM_{10} and $PM_{2.5}$ from person transport in three different scenarios were determined. The scenarios were: 1) the private car scenario, where the main growth in total person transport is to be met with a strong increase in the use of private cars, 2) the public transport scenario, where the increase in total person transport is to be met with a strong increase in the public transport, and 3) the sustainability scenario, with a reduction in total person transport, increased share of public transport and walking/bicycling, and reduced share of private car use.

5. Environmental Reporting and Transport – the case of a Public Transport Company.
   The article is accepted for publication in the international journal "Business Strategy and the Environment".

The article discusses corporate environmental reporting in the field of transport. In addition to analysing the issue in general, the article covers empirical material from Oslo Sporveier. The relations between industrial ecology and transport are studied through the development and implementation of environmental reporting systems for a public transport company. The process of preparing the year 2000 environmental report for the company is described. This presentation also includes examples of actions for improving the environmental performance of the company, and indicators for monitoring the progress from year to year. The article has empirical basis in separate studies of the employee's company travels, daily travel to work, and the purchasing of energy. The article also shows how the company is using societal accounting to show its responsibility as an important societal actor, improving the stakeholder dialogue and providing knowledge at the political level.

The chapter that follows after the four scientific journal articles is a conference paper with a separate set of *notes*. The texts in these notes were not included in the paper presented at the conference due to restrictions regarding the length of the paper. They are included here to give a more complete presentation, both of the theoretical and empirical material the paper is based on.

The conference paper is:

6. Alternative Energy in Transport Companies. Industrial Ecology Perspectives on Resource- and Implementation-limits of Biological Fuels.
   The paper is published in the proceedings from the 8th European Roundtable on Cleaner Production in Cork, Ireland, October 9-11th, 2002.

The paper addresses the relations between industrial ecology and alternative transport energy. The industrial ecology and transport relations are discussed from the perspective of bus companies' connection to biological renewable energy systems and in the form of implementation strategies for biological renewable energy systems in the transport sector in general. Limits and barriers to the use of biodiesel from rapeseed, and alcohols from wood, are discussed from industrial ecology perspectives. The paper presents results from the two projects "Biodiesel in heavy duty vehicles in Norway – Strategic plan and vehicle fleet experiments" and "Motor-alcohols from wood resources in heavy duty vehicles. A Nordic project on market-penetration through stakeholder group networks". The mobile energy conversion is the key to the connection to industrial ecology for transport companies. The most important barriers to implementation of biodiesel in Norway are presented, in terms of national barriers, company barriers, barriers connected to driving and starting in cold weather, and biodiesel production barriers. The effect on the emission of greenhouse gases from a transition to use of biodiesel is also discussed. The paper also discusses the experiences with the use of stakeholder group networks for identification and resolvement of barriers to wood-based motor-alcohols.

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2. An Industrial Ecology Typology

2.1. Introduction

Industrial ecology is a wide approach applied to the concerns of natural resource exploitation and environmental impacts from industrial activities. The concept is emerging as an umbrella for industrial leaders, academia and government agencies. A wide range of interpretations and understandings[6] of the concept exists. The aim of this chapter is to elucidate these different understandings. This is done through the establishing of an industrial ecology *typology*[7] where the different understandings are classified according to their main characteristics.

There are three main reasons for establishing the typology. The first two reasons are connected to theoretical aspects of the thesis:

1. The establishing of a typology of industrial ecology is one way of carrying out a review of the main literature of industrial ecology. The typology gives a presentation of the most important literature contributions to industrial ecology.
2. The establishing of the typology constitutes a theoretical contribution to the industrial ecology literature. It is thus a form of theory building, which aims at improving the understanding of the concept industrial ecology.

The third reason is of a more instrumental character, in that it serves the purpose of identifying transport problems connected to the various understandings of industrial ecology:

3. The typology can be considered a basis for illustrating problems related to transport. The fact that there are many different ways of understanding

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[6] The concept *understanding* is mainly limited to usage in the human- and social sciences. The German philosopher Wilhelm Dilthey claimed that there is a main difference between human sciences and natural sciences in terms of the development of knowledge (Dilthey, 1883). The natural sciences are studying material phenomena that can be observed from the outside and be explained with reference to physical regularities ("the laws of nature"). The human sciences are studying human relations, experiences and manifestations, with the goal of *understanding* these phenomena from within.

The German sociologist and political economist Max Weber considered an *understanding* as a part of the social science that aims at explaining social actions in relation to the intentions of the actors (Weber, 1994). Weber distinguishes between direct *observational* and *explanatory* understandings. The direct observational understanding is an understanding that is based on the ability to grasp the meaning of a given act. The explanatory understanding is directed towards revealing the motive an actor attaches to an action, or the average meaning of the actions of several actors, or the theoretical constructed meaning of a certain type of actions.

[7] The term *typology* is used for a classification scheme, which is based on grouping of phenomena into ideal categories, according to a set of common characteristics. Sets of dichotomised mutual excluding variables are commonly used to establish a typology. Typology and taxonomy are two opposed methods of classification. Typology classifies according to the sensuously given characteristics of the thing, while taxonomy classifies objects according to the origin (genesis) of the thing. Among the most known typologies in the social sciences is Weber's typology of social action as value-rational, intentional-rational, affectual or traditional (Weber, 1968). Karl Marx' typology of societies as tribal, antique, feudal, capitalistic or communistic is another example.

> industrial ecology makes it difficult to identify the associated transport problems, without first characterise each of the main understandings of the concept. The typology thus establishes a basis for illustrating transport problems connected to the concept industrial ecology.

In the following part of this introduction it will be explained how the typology has been established. This is in part based on earlier contributions by Suren Erkman (1997) and Thomas Graedel (1994) to the establishing of typologies for the understanding and interpretation of the concept.

The next part of the introduction explains how the characterisation of the different types of understandings is carried out. The elements used in the characterisation of the types, and the background for the choice of the elements, are also described.

The final part of the introduction is a presentation of the approach used to characterise the transport themes connected to the different understandings of industrial ecology.

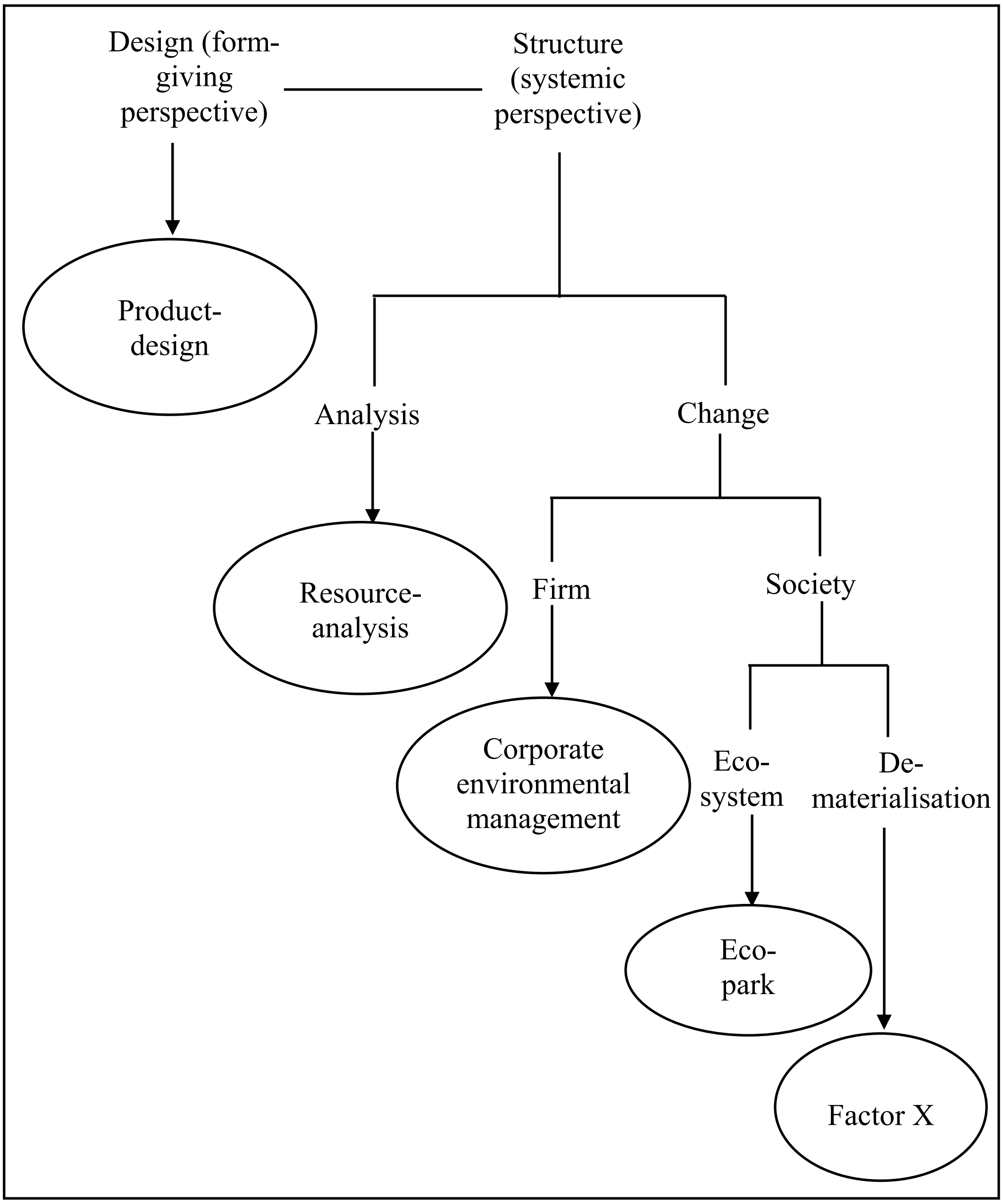
Subsequently after this introduction, each type is presented. This is carried out by, for each individual understanding, first presenting the central contributions, then the key characteristics, and finally a brief discussion of the transport themes connected to the type.

At the end of Chapter 2 is included a comparison of the different understandings of industrial ecology. Also the transport themes in the different understandings are compared, followed by a more extensive discussion of transport connected to the different understandings of industrial ecology.

2.2. Establishing of the types

This sub-chapter explains how the typology of industrial ecology understandings has been established. The process of identifying the various types in the typology is shown schematically in *Figure* 4. In the figure the types are shown in oval boxes.

Figure 4 *Schematically presentation of the process of identifying the various types in the typology*



First, the commonly made distinction between design (or: form) and structure is applied. Design is a form-giving aspect, connected to the appearance and forming of industrial products and processes. Structure is a perspective applied to the inner organisation of the industrial systems, and the interrelations between their elements. The application mainly of the design perspective in industrial ecology, leads us to the first distinct type, the *product-design* understanding of industrial ecology. This is an understanding of industrial ecology as mainly consisting of design of products and processes with improved environmental characteristics, more compatible with natural ecosystems.

The structure perspective is applied either in the form of analysis or change. The understanding of industrial ecology as mainly consisting of analysis of resources and their flow through society brings us to the second distinct type, the *resource analysis* understanding of industrial ecology. In this understanding of industrial ecology the analysis of resource flows gives knowledge, which can form a basis for obtaining changes and improving industrial metabolism. This is distinctly different from those understandings of industrial ecology where the focus is on developing and implementing the changes to industrial structures.

A distinction is further made between changes at the company level and the societal level. At the level of the individual company, industrial ecology can be understood as a framework for the management of environmental issues in the companies. This brings us to the third distinct type, the *corporate environmental management* understanding of industrial ecology. This understanding of industrial ecology as a framework for corporate environmental management is distinctly different from the understanding of industrial ecology as aiding in obtaining changes to larger segments of society.

At the level of society, a distinction made by Erkman (1997) is applied. Erkman points out that industrial ecology has evolved into two main directions:

1) *Eco-industrial parks and islands of sustainability.*
   This direction of industrial ecology is characterised as constituting the most immediate application of the ecological concept of food web between companies. The analogy is drawn to the natural food web by the creation or retrofitting of industrial zones where one company uses waste or by-products of another company as its resources.

2) *Dematerialisation (and decarbonisation).*
   This direction focuses on the development of concepts and strategies for the optimisation of the flows of materials within the economy, which is largely based on technological evolution. This implies an increase in resource productivity, or dematerialisation, and the strategy for selling of services instead of products. The main approach in the field of energy is the "decarbonisation" strategy, with the objective of decreasing the relative amount of carbon in fuels, meaning a shift from coal to petroleum, then to natural gas and ultimately to solar energy and hydrogen.

The former direction, in which an ecosystem approach is taken, leads us to the fourth type, the *eco-park* understanding of industrial ecology. In this understanding the natural ecosystems are explicitly used as models for organisation of industrial activities. The latter direction, the direction of dematerialisation, leads us to the fifth type, the *factor X* understanding[8], where industrial ecology mainly is interpreted as a way of achieving dematerialisation of society.

The five understandings represent in total a description of the field industrial ecology drawn from the international literature. A question can be asked if this is based on a wide or narrow interpretation to industrial ecology. From a narrow

[8] In the term factor X reduction in resource use, the X denotes a number, usually between 4 and 50. The factor 4 and factor 10 are the most common. A high X-value indicates a high degree of dematerialisation.

perspective it would be possible to argue that the *corporate environmental management* and *factor X* understandings are only weakly connected with the field of industrial ecology. In much of the literature covering corporate environmental environment and factor X the connection to industrial ecology is not explicitly made. There are however justifiable reasons to widen the typology by including these two understandings. As will be shown in the presentation of the most central contributions to these two understandings (Chapter 2.6.1 and 2.7.1) there are overlap and commonalities between their key principles and elements of industrial ecology. They clearly fit within the frame of industrial ecology. A very narrow frame for industrial ecology, would not reflect the various interpretations, and probably give a poorer foundation for throwing light on transport problems connected to industrial ecology. Joseph Huber also points to the dangers of drawing the lines around industrial ecology too narrow. He claims that it is unfortunate that industrial ecology often is understood in a rather narrow sense as:

> "Redesigning industrial processes so they mimic natural ecologies where there is no waste because all outputs become inputs for something else".
> Huber (2000, p. 282)

There is also another important reason for the choice of a wider interpretation of industrial ecology. By excluding *corporate environmental management* and *factor X* and limiting the typology to the three remaining understandings, a tradition dominated by the United States would be the result. The industrial ecology typology would then be too limited and not sufficiently reflect important traditions and understandings in a European context. *Corporate environmental management* has strong historical basis in Britain, for example, while the *factor X* concept originated to a large extent in Germany.

2.3. Characterisation of the types

In this section it is explained how the characterisation of the different understandings of industrial ecology is carried out. The characterisation has basis in earlier reviews of the industrial ecology literature (O'Rourke et al., 1996; Erkman, 1997).

In the characterisation of the industrial ecology understandings several sets of conceptual pairs of elements are applied. Some of the elements applied by O'Rourke et al. (ibid.) are used, but supplemented with other elements found more suitable for the characterisation in this typology.

The conceptual pairs of elements used in the characterisation are of two categories. The first category consists of pairs of *formal elements*. These are used to express the formal characteristics of each of the various understandings of industrial ecology.

The set consists of the following contrasting pairs of formal elements:

1. Limited ↔ Total
2. Gradual (extensions) ↔ Radical (new paradigm)

The formal element *limited* is used to characterise an understanding as focusing on limited (or minor) changes in existing systems. The contrasting element *total* is used to characterise those understandings of industrial ecology that focus on much larger transformations of industrial activity. A parallel can be made to the science of planning, where limited (or incremental) planning implies planning in small segments at a time, often executed with limited long-term perspectives, and as ad hoc adjustments to previous plans. Total planning is a more comprehensive planning process where changes in larger systems are projected in one single planning process. The total planning is comprehensive and requires clearly defined goals. An example used by O'Rourke et al. (1996) of limited changes for industrial firms is the continuation of pollution prevention efforts, while total transformations consist of fundamental re-thinking and re-design of products, services and processes.

The second contrasting pair of conceptual formal elements expresses the characteristics of each industrial ecology type as either constituting *gradual extensions* of efficiency improvements underway in industry or a *radical new paradigm* that must be embraced "if we are to save the planet from the impacts of industrial development" (ibid.). Initially the gradual extensions to radical pair might appear quite similar to the *limited – total* dimensional axis, but it will be shown that they differ in several ways. The gradual-radical conceptual pair expresses, to a larger extent than limited-total, the characteristics of the way of carrying out a change. It is more oriented towards understanding, rather than merely describing, a process of change. In other words, the gradual-radical dimension is used in seeking to obtain knowledge of the type of changes in question. There is in addition a distinct difference between total and radical. A radical approach does not have to be total or comprehensive, and a total change does not have to be radical, for example if it occurs over a long time period.

The second category of contrasting conceptual pairs applied in the characterisation of industrial ecology understandings is made up of *substance elements*. For the purpose of this characterisation, the following contrasting pairs are used:

1. Nature integration ↔ Nature analogy
2. Material ↔ Energy
3. Product ↔ Production / Production system

The substance element *nature integration* expresses that the industrial activities are integrated with the natural ecosystems. Best possible integration, i.e. minimal encroachments in natural ecosystems is understood as the optimal situation. A life-cycle approach to industrial product and processes is applied in this context, including resource use connected to extraction and transport of raw materials, production, waste, distribution and use of product, and finally recycling. An example of where the principle of nature integration is applied is in a product made exclusively from natural biological material. This product is better integrated with natural ecosystems than the case is with a comparable synthetic product, due to the renewable raw material composition and biodegradability.

The interpretation of industrial ecology as a *nature analogy* implies that the natural ecosystems are used as models for industrial activities. In a natural ecosystem there is interplay between the organisms, through a network where waste from one organism is turned into nutrient for another organism. Everything is fuelled by solar energy. In the nature analogy interpretation the organisms are replaced with industrial facilities, in such a way that the interplay now is between the industrial facilities. Waste from one industrial locality (or factory) is used as raw material for another industrial activity. If the analogy is to be completed, only solar energy can be an acceptable primary source of energy. The exploiting of natural deposits, such as obtaining energy from combustion of fossil fuels, will have to be replaced by an energy usage based on renewable sources, all which are based on the sun as primary energy source. *Nature analogy* is thus used to characterise an understanding of industrial ecology where the ecosystems in nature are used explicitly as models for the organisation of industrial activities. Even though this principle of modelling according to systems found in nature is central to the core of the concept industrial ecology, the focus on this principle varies between the different understandings of industrial ecology. The analogy-element is thus used to characterise this focus as opposed to the other element of this conceptual pair, the nature integration.

The pair of substance elements *energy – material* is used to express relative emphasis on energy vs. material in the various understandings of industrial ecology. The substance elements energy and material are used in many other discussions of industrial ecology (e.g. O'Rourke et al., 1996; Connelly and Coshland, 1997).

The third pair of conceptual substance elements is used to express each understanding's focus on *products* or *production / production system.* The main focus in some of the understandings of industrial ecology can be on changing the functioning of products to reduce the release of toxic substances during their lifetime, for example, or to make the products more recyclable. The emphasis is then on the products. Another different focus is on improving the production or production systems[9] by reducing emissions and waste from industry. This can be obtained by making changes to the processes and the way industrial facilities are located relative to each other, to improve the possibilities for the utilisation of industrial waste in other industrial processes.

As described in connection with the establishing of the five understandings, a differentiation is made between *analysis* and *change*. This differentiation leads to three industrial ecology types strongly connected to changes (*Figure 4).* They are 1)Corporate environmental management, 2)Eco-park, and 3)Factor X. In addition to these three types, there is also a strong element of change in the Product-design understanding. This is due to this understanding's focus on design of products and processes with improved environmental characteristics, which are ways of changing the connections between industry and natural ecosystems. Studies of changes to society often include analysis of *actors* in addition the structural

[9] It must be emphasised that there is a main difference between production and production systems. The latter is much more comprehensive than the former. A *production system* also include the energy production, transport activities etc., activities which it is possible to exclude with the more limited focus on *production* only.

conditions (Parsons, 1949, 1951; Giddens, 1984). The involvement of actors is important in connection with societal changes. Thus, in the characterisation of the four industrial ecology understandings connected to change, the actor-perspective is described. This is carried out by asking the following superior question:

- What is the actor perspective in the type?

This superior question is answered through the two operational questions:

- Which actors are involved?
- How are the actors involved?

The fifth understanding in the typology, the resource-analysis, is not directly connected to societal changes. It is more focused on establishing necessary knowledge for understanding the flows of resources in society. The actor-perspective is thus not described for this type.

As touched initially, the aim of this typology is to give an overall picture of various understandings and traditions in industrial ecology, and to use this as a basis for illustrating problems related to *transport*. The transport problems are addressed in each understanding of industrial ecology by asking the following questions:

1. How is transport included, and what focus is there on transport in the understanding?
2. What conditions and limits are there for handling transport questions in the understanding?

The first question is connected to the main transport issues in each understanding. It is discussed through a descriptive presentation. The question of how transport is included is answered using the systematic of the *efficiency-pattern-volume* dimensional axis previously presented in *Figure 2*. The last question concerns *the limitations and conditions for including transport* in each understanding. This issue is approached through a discussion of the transport problems and the limits for including transport considerations in the various understandings.

2.4. Industrial Ecology Type: Product-design

2.4.1. Central contributions to the product-design understanding

The product design understanding of industrial ecology can be traced back to the work in the Japanese Ministry of International Trade and Industry (MITI) in the late 1960’s. About fifty experts from industry, public sector and consumer organisations explored the possibilities of making the Japanese economy less dependant on exploration of material resource use, and rely more on information and knowledge. The first report from this group is a Japanese document of more than 300 pages, but a summary in English was published by the urban engineer Chihiro Watanabe (MITI, 1972). The basic principle of the early Japanese thinking on industrial ecology was to replace material resources with technology and increase the efficiency of resource use. These early ideas of industrial ecology were put into practice in Japan aiming at improving the productivity of the Japanese national economy.

The contribution by Hardin Tibbs (1992) "Industrial Ecology: An Environmental Agenda for Industry" was important in disseminating the core principles of industrial ecology, mainly due to the use of the language of the business world. The presentation of industrial ecology was in addition done in a rather summarised form and published widely, both by Arthur A. Little in 1991, in Whole Earth Review in 1992 and by Global Business Network in 1993.

In one of his many contributions in the field of industrial ecology, John Ehrenfeld (1994) has termed industrial ecology "a strategic framework for product policy and other sustainable practices". The aim was to use the industrial ecology principles of DFE, loop-closing[10] and life-cycle assessment[11] (LCA), in forming product policies. Ehrenfeld's approach is directed towards "aligning product policy with long-term industrial system evolution" and "balancing input and output with ecological capacity".

Thomas Graedel and Braden Allenby wrote the first student textbook on industrial ecology in 1995 (Graedel and Allenby, 1995). The book was written as a tool for engineering and designing of industrial products. It includes, in addition to issues on material and energy, a description of the main industrial process residues. Trends in technology are presented, likewise risk assessment and environmental interactions during product use. The central industrial ecology methods LCA and DFE are described in detail, and also their application for various specific products. This contribution is mainly limited to product and production aspects, with the former being the main focus. Larger system considerations are only to a smaller extent covered, and long-term alterations in the development of the industrial society are outside the approach taken by the authors.

Three years later, the same authors wrote the book "Industrial Ecology and the Automobile" (Graedel and Allenby, 1998). This was a thorough contribution to the industrial ecology aspects of the automotive production and the automobile product itself. The book mainly focuses on guiding engineering students in designing products through the application of DFE and LCA. It presents methods for assessment of material consumption and energy use using "streamlined versions of LCA" and the "weighted matrix" approach. Even though larger system considerations are touched, this is only done briefly, without leaving the main

[10] By "loop-closing" is understood the process of moving from linear to cyclic material flows. This is facilitated by increased re-cycling and re-use of industrial residuals in place of generation of unusable waste-flows.

[11] Life-cycle assessment usually follows a four-step methodology consisting of scoping, inventory analysis, impact assessment and improvement assessment. Scoping is a process of identifying the goals that motivate the assessment and determining the proper boundaries of the study. The inventory analysis is an accounting of the resource requirements for a particular product, process or industry from virgin materials extraction to final deposition. The impact assessment is conducted to relate the inventory data to specific environmental concerns. Finally, the improvement assessment (or interpretation phase) identifies those aspects of the materials life cycle that might be most amenable to mitigation, or evaluates the potential for application of new strategies that offer the greatest leverage for environmental benefits (Saeger and Theis, 2002).

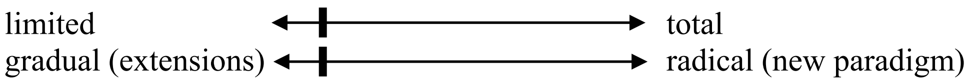
focus of the design of the automobile as an industrial product. More comprehensive changes in the development of transport in industrial societies are absent in the approach.

2.4.2. Key characteristics of the product-design understanding

The understanding of industrial ecology as mainly a framework for design of industrial products can be characterised as a *limited* approach to changing existing systems. The design of products is carried out in small areas at a time, with the long-term perspectives and change to the total industrial systems receiving relatively less focus. This understanding is also characterised as mainly focusing on *gradual* extensions and improvements in designing products with less environmental impacts along the product chain, rather than radical changes or a new paradigm.

The key formal characteristics of the product-design understanding of industrial ecology is summarised in *Figure 5*.

Figure 5 *Formal characteristics of the product-design understanding of industrial ecology*

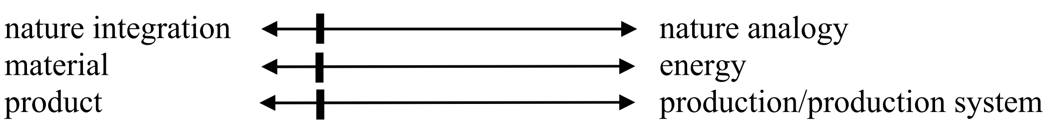


The product-design understanding can be characterised as applying the principle of *nature integration* rather than the contrasting concept nature analogy. This is due to the fact that the focus is on designing products (and processes) with less environmental impacts, thus better integrated with nature. There is more focus on *material* use than on energy use in this understanding of industrial ecology. Energy is certainly important, but it is over-shadowed by material considerations in this understanding. Illustrative of this disproportionate handling of energy issues in this understanding of industrial ecology, is the presentation by Graedel and Allenby (1995, p. 114) of a table of "The total industrial ecology cycle". The quite comprehensive table does not include even a reference to energy use.

When considering the axis with the substance elements products and production system, the product design understanding has a main focus on *products* rather than the production or production systems.

The key substance characteristics of the product-design understanding of industrial ecology are summarised in *Figure 6*.

Figure 6 *Substance characteristics of the product-design understanding of industrial ecology*



2.4.3. Actors in the product-design understanding

The actors involved in the product design understanding of industrial ecology are first of all the industrial engineers and designers involved in the design and development of new products with improved environmental performance, so-called eco-design. The public sector and consumer organisations also play important roles as pressure groups in demanding more environmentally friendly products, for example eco-labelled products. Branch organisations can function as actors through influencing the product design by setting standards and codes of conduct pertaining to industrial producers. Responsible Care programs and Product Stewardship codes developed by the Chemical Manufacturers Association are examples of this.

2.4.4. Transport and the product-design understanding

The product-design understanding of industrial ecology includes some transport issues. Transport is however not a central issue in this understanding, and is usually overshadowed by other considerations. The contributions by Gregory Keoleian et al. (1997), and Graedel and Allenby (1998) are two of the few examples where transport is included in this understanding of industrial ecology.

Transport in the contributions to the product-design understanding is mainly limited to design of the automobile. In this understanding industrial ecology can thus be considered as a framework for the design of transport means, with a main focus on automobiles. Life-cycle perspectives are applied on material and, to a lesser extent, energy use in the design of the automobile product (Keoleian et al., 1997; Graedel and Allenby, 1998). Improvement in the materials use in the vehicles is one central issue in this understanding. The changes in vehicles and components have resulted in some efficiency improvements over the last decades. Changes made to the engines and fuel systems have reduced the fuel consumption, exemplified by a 12% reduction from 1980 to 1990 in the fuel consumption of the average new automobile in the USA (Keoleian et al., 1997, p. 56). The continuation of this decreasing trend is however not that evident, as will be discussed later (Chapter 2.10.2).

The transport issues in the product-design understanding of industrial ecology are on the *efficiency* end of the *efficiency-pattern-volume* dimensional axis. The focus is on technical aspects of improving the efficiency of the automobile. The problem of the increasing amounts of air pollution and emission of climate gases from transport is, in this understanding of industrial ecology, addressed mainly by technical approaches. These include the design of new motor-technologies for increasing the energy-efficiency and reducing the emissions.

2.5. Industrial Ecology Type: Eco-parks

2.5.1. Central contributions to the eco-park understanding

In a special issue on "Managing Planet Earth" of the popular scientific monthly magazine Scientific American, Frosch and Gallopoulos (1989) published the article titled "Strategies for Manufacturing". In this contribution the notion of an *industrial ecosystem* was brought into the popular literature[12]. The authors presented the concept of industrial ecosystem as a system where “wastes from one industrial process can serve as the raw material for another, thereby reducing the impact of industry on the environment”. This is in essence a description of the principles of an industrial “ecological” cluster or more commonly termed, an eco-park.

Frosch (1992) suggests that the strategy for reducing the flow of materials is to cascade waste and products at the end of their life. Materials are passed down the industrial food chain through a series of more and more degraded uses. Plastic products are given as an example where this strategy is applied. The extreme difficulty of recycling plastics, due to the complexity of the composition, makes cascading a viable alternative to incineration and land filling. This contribution by Frosch focuses mainly on developing industrial systems where by-products and wastes can be utilised.

Ernest Lowe and co-workers at Indigo Development have made several contributions to industrial ecology in general and the development of industrial ecoparks in particular (Lowe and Evans, 1995; Lowe, 1997; Lowe et al., 1997a, 1997b). Particularly the U.S. EPA sponsored “Eco-Industrial Parks: A Guidebook for Local Development Teams” (Lowe et al., 1997a) is a central contribution to the establishing of industrial ecosystems, or in Lowe’s terminology “eco-industrial parks”. The contribution includes guidelines for initiating the establishing of eco-industrial parks and integrating these systems into economic development programmes in communities. These guidelines encompass setting environmental performance objectives, develop planning, financing and recruitment strategies, and designing management systems for eco-industrial parks. The contribution also includes a survey of options for the design of infrastructure, buildings and support services. Furthermore, the book includes material on actual cases of eco-industrial parks, plus extensive organisational and bibliographic resources. The main focus in the contributions by Lowe is on providing practical guidance to establishing industrial ecosystems (eco-parks).

In Nelson Nemerow’s book titled “Zero pollution for industry – waste minimization through industrial complexes” the concept of “zero”-emissions clusters is used extensively for industrial facilities co-existing in industrial ecological complexes (Nemerow, 1995). The concept is based on “loop-closing” of industrial waste streams by trading wastes between each industrial facility in the cluster. Nemerow’s term for these systems is “environmentally balanced industrial complex” (EBIC). A wide range of different types of EBICs is presented in the book, each with their specific composition of different industries and waste trading systems.

[12] What might be the earliest occurrence of the concept “industrial ecosystem” is found in a paper by the American geochemist Preston Cloud (1977). The paper was dedicated to the Rumanian-American economist Nicholas Georgescu-Roegen, who has emphasised the importance of considering material flows in the human economy from a thermodynamic perspective (1971).

In the 1997-contribution by Lloyd Connelly and Catherine Coshland it is argued that *exergy*[13]-based considerations can provide a useful framework for analysing waste cascading and recycling in industrial ecosystems (Connelly and Coshland, 1997). The authors show that exergy-based considerations can be used to distinguish a cascaded waste from a recycled waste and to determine what waste cascading can – and more importantly cannot – accomplish. While waste cascading has the potential to reduce the demand for resources, exergy removed from materials during consumption must be returned to those materials if they are to be recycled – i.e. returned to their pre-consumed quality level. The authors point out that the closing of material cycles require full recycling of material exergy, and not merely re-use of waste materials in any available feedstock. They point to the fact that with a failure to address the irreversible nature of the consumption process, the loop-closing theory will only capture a limited aspect of the integrated material-energy strategy necessary to achieve sustainable material management. This contribution thus focuses on improving the fundamental understanding of systems for recycling and cascading of waste.

[13] Exergy is the common term used for analysing flows of both energy and matter through society. The meaning of the term can be illustrated by the following examples (Wall, 1997):

A system in complete equilibrium with its environment has no exergy. There is no difference in temperature, pressure, or concentration etc. that can drive any processes. Thus, a waste flow, of any kind, with no exergy, does not influence the environment.

The more exergy a system carries, the more it deviates from the environment. Hot water e.g. has a higher content of exergy during the winter than it has on a hot summer day. A block of ice carries hardly any exergy in the winter while it does in the summer. This fact was the basis for a prosperous trade of ice in the last century, when ice was transported by boat from North America to Europe.

When a physical resource, i.e. energy, matter or information, looses its quality, exergy is destroyed. The exergy is the part of the resource that is useful in the society and therefore has an economic value and is worth taking care of.

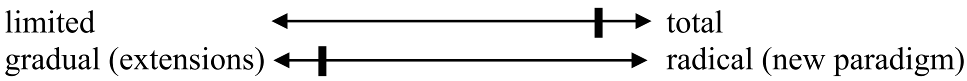
Almost all exergy, converted in the thin layer on the earth's surface, where life can be found, derives from the sun. Sun-light, which is rich in exergy, reaches the earth. Much of it is reflected, mainly the harmful ultraviolet light by the ozone layer. The energy that is absorbed on the earth, partly by photosynthesis in the green plants, is converted and finally leaves the earth with no exergy content relative to the earth. The net exergy absorbed by the earth is gradually destroyed, but during the destruction it manages to drive the water/wind systems and the life on earth. The green plants absorb exergy and convert it via photosynthesis into chemical exergy. The chemical exergy then passes through different food chains in the ecosystems. Exergy is consumed on all levels of the food chain, and microorganisms live on the last level. There exists no waste i.e. all exergy is being taken care of and efficiently used by the living nature.

A concentrated mineral deposit "contrasts" with the environment and this contrast increases with the concentration of the mineral. The mineral is thus a carrier of exergy. When the mineral is mined, the exergy content of the mineral is kept constant, and if it is enriched, the exergy content increases. A poor deposit of mineral contains less exergy and can accordingly be utilized only through a larger input of external exergy. Today this substitution of exergy often comes from exergy forms such as coal and mineral oil.

2.5.2. *Key characteristics of the eco-park understanding*

The understanding of industrial ecology as a framework for organising industrial activity into clusters of recycling and waste trading is characterized as focusing on *total* transformations of industrial systems rather than on limited changes to existing activities. The establishing of new industrial complexes with the aim that they function as "industrial ecosystems" is a main focus here. The approach in general is however on individual recycling systems and industrial ecosystems, and not on broader aspects of recycling such as by way of the concept recycling society[14]. The establishment of eco-parks is understood as *gradual extensions* of current practices underway in industry rather than a radical new paradigm. The key formal characteristics of the eco-park understanding of industrial ecology is summarised in *Figure 7*.

Figure 7 *Formal characteristics of the eco-park understanding of industrial ecology*



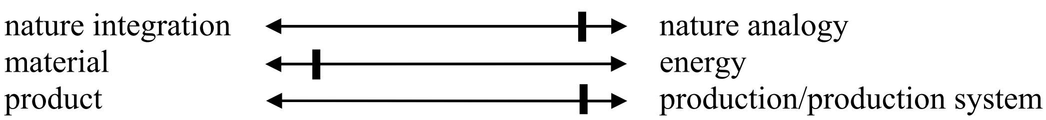
The eco-park understanding can be characterised as applying the principle of *nature analogy* rather than nature integration. In this understanding the organisation of industrial activities, to greatest extent, should use natural ecosystems as model. Nature's resource cycles as model for industrial resource cycles make recycling a main theme in this understanding of industrial ecology. This applies both for nature's sources of energy and for raw materials for industrial products. For the sources of energy it follows, from the principle of recyclability of sources fuelled by solar energy, that a change is to be made from today's exploitation of fossil fuels to energy systems based on renewable energy sources, such as bio-, wind- and solar energy.

An imbalance between material and energy issues is evident in this understanding of industrial ecology. The energy issues are not frequently addressed, but overshadowed by *material* considerations.

When considering the pair of substance elements products and production / production system, the eco-park understanding has a main focus on *production and production systems* rather than on the products being produced.

The key substance characteristics of the eco-park understanding of industrial ecology are summarised in *Figure 8*.

Figure 8 *Substance characteristics of the eco-park understanding of industrial ecology*



[14] "Recycling society" is a term used for a society where the classical one-way flows of material resources are kept to a minimum, and recycling is established on an overall societal level.

2.5.3. Actors in the eco-park understanding

The industrial companies taking part in an industrial ecological cluster (eco-park) are playing an important role in the functioning of these structures. The companies can have the function as material suppliers, product manufacturers, transport- or infrastructure operators (incl. maintenance) or product dismantler/recycler. The willingness to share, with the other member-facilities, the information about the composition of the waste streams is crucial for a well functioning eco-park. But in addition to the participating industrial companies, a facilitator is often needed for the forming of an eco-park. A facilitator is an actor whose function is to stimulate to the forming of a recycling network and co-ordinate the waste-producers and the waste-consumers (scavengers). A facilitator can be one of the participating industrial companies, but can also be a neutral part, for example the local or regional development council.

2.5.4. Transport and the eco-park understanding

In the eco-park understanding of industrial ecology transport is not a main focus. It is rather rare within this branch of the industrial ecology literature to encounter discussions of transport themes. Rather the failure of addressing transport problems is more the general rule.

In the few instances when transport problems are included in the eco-park understanding, these can be characterised as being relatively close to the *efficiency* end of the *efficiency-pattern-volume* dimensional axis. One example connected to the establishing of the "closed-loop" systems concerns the recyclability of automobile components. A promising energy-conversion system for future vehicles is based on fuel cell technology. For the operation of vehicles based on fuel cells, a system for temporarily storage of electricity is however required[15]. True "closed loop" systems for the recycling of future batteries are required. Björn Andersson at Chalmers University points to the fact that processes to recover metals exist or are under development for most vehicle battery types (Andersson, 2001). However, some of these processes are not compatible with "closed loop" recycling. As an example, nickel used in NiCd batteries is currently not recycled to yield nickel of a grade suitable for battery manufacturing, but is downgraded to ferronickel for stainless steel production. This is an example where a more complex material composition is used (NiCd vs. lead-acid battery) aiming at improved performance, but resulting in decreased recyclability.

Another example in the eco-park understanding is illustrative of this understanding's lack of volume-considerations connected to transport. The approach to developing industrial ecosystems taken by Michael Moldaver (1999) includes developing a learning tool in the form of the board game "The Green Game". This game is claimed to function as a strategic simulation of the automobile life-cycle, where the teams are divided into the four primary components of the automobile industry's supply chain; supplier, manufacturer, operator and dismantler-recycler. The participants are to use the industrial ecology

[15] Fuel-cells do not operate well in cold ambient temperatures. An electric battery in combination with the fuel-cell technology is required for satisfactory operation in cold weather. The battery is in addition required for temporarily storage of re-generated brake energy.

principles of waste minimisation, pollution prevention, design for environment, recycling, full cost accounting, design for sustainability, life cycle assessment, environmental management and design for disassembly. The goal is that the participants shall synthesise and implement "whole-system strategies". This is however to be carried out without any considerations at all of transport-forms, -volumes or –distances in the system. It is quite obvious that these so-called "whole-system strategies" are only "part-system strategies" with the environmental impacts of the transport volumes completely missing.

2.6. Industrial Ecology Type: Corporate environmental management

2.6.1. Central contributions to the corporate environmental management (CEM) understanding

Thomas Gladwin, later on the editorial board of the Journal of Industrial Ecology, pointed in 1993 to industrial ecology as one of the most significant trends in corporate environmentalism (Gladwin, 1993). This was done in the book "Environmental Strategies for Industry. International Perspectives on Research Needs and Policy Implications", authored by the two founders of the Greening of Industry Network[16] (Fischer and Schot, 1993). Gladwin particularly referred to the industrial waste "food-chain" involving Novo Nordisk, Kemira, Statoil, and the Asnaes power plant in Kalundborg. The characterization of industrial ecology as an important trend in corporate environmentalism was based on a survey of major newspapers and environmental periodicals. This contribution, through the positioning of industrial ecology as a major trend within the greening of business[17] concept, was important in the developing of the understanding of industrial ecology as a framework for environmental management.

Bruce Paton (1994) has raised the question of what industrial ecology principles imply for the environmental management in firms. The author claims that the principles of industrial ecology can be important in an integrated management approach. In such an approach, environmental values are internalised within the design of products and processes. This can, according to Paton, only be obtained if a clear vision exists of what needs to be accomplished. Furthermore, a workable plan, effective business processes, and an understanding of the financial impact of reuse and recycling, are all requirements of the integrated management approach. It is also pointed to the fact that traditionally little attention has been paid to the resource usage implications of companies' distribution systems. The life-cycle approaches of industrial ecology contribute to higher focus on this aspect of the production system. Paton's contribution is thus an example of an approach to corporate environmental management where industrial ecology principles are found particularly valuable.

[16] The Greening of Industry Network is a network fronted by business scholars and industry leaders, originated by Kurt Fischer at Tufts University in the United States and Johan Schot at University of Twente in the Netherlands.

[17] The "greening of business" is here understood as the continuous improvements in the environmental performance of business corporations, an issue being dealt with in the Greening of Industry Network.

As a central industrial ecology contributor Allenby (1997) analyses the responses of private firms to external challenges. Principles of industrial ecology, such as LCA, DFE, and product take-back policies are such challenges that firms must adapt to. The author points to corporate environmental codes of behaviour which function to guide corporate environmental management. Examples of these codes that are beginning to reflect the principles of industrial ecology include the principles of the Business Charter for Sustainable Development developed by the International Chamber of Commerce in 1991 and the Responsible Care Program and Product Stewardship Code developed by the Chemical Manufacturers Association (CMA) in the USA. The CMA Product Stewardship Code includes, for example, a requirement that CMA members encourage distributors and direct product receivers to implement proper health, safety, and environmental (HSE) practices. This is an indirect extension of responsibilities of the producer to include the use stage, with a desire to improve the life-cycle impacts of the products. Allenby is through this contribution giving improved insights in the functioning of industrial ecology as a framework for corporate environmental management.

In an editorial in the Journal of Industrial Ecology, the important industrial ecology contributor John Ehrenfeld (2001) discusses the functioning of environmental management systems (EMS) from an industrial ecology perspective. He argues that EMS and industrial ecology have existed separately from each other, and that EMS historically have focused on single firm issues. Industrial ecology has focused on the connectedness between firms. According to the author, this is one main reason why EMS literature not has been found relevant enough to be accepted in the Journal of Industrial Ecology. Ehrenfeld argues that this trend is changing, and EMS literature has much to contribute to the field of industrial ecology. He also, on the other hand, considers industrial ecology to be a strengthening factor for virtually any EMS by providing a systematic framework for assessing environmental impacts. In this contribution it is argued that industrial ecology principles applied to environmental management in firms opens up new possibilities for strategic vision and system-oriented approaches. Ehrenfeld points to the fact that EMS based on the standard ISO 14001 is relatively weak in forcing change, but within the framework of industrial ecology the normative aspect is stronger, which aids in promoting sustainability.

Joseph Huber (2000) considers EMS as a “transitional strategy for sustainable development”, connected to the process towards an industrial ecology. *Sufficiency* is the sustainable development strategy of conservation advocated by NGOs, while *efficiency* is the industry approach of improving the input-output relations of processes and product chains. Huber suggests that a third strategy, the strategy of *consistency,* is the joint strategy of the future for government, business and research. It leads to a consistent metabolism in an industrial ecology; meaning that the industrial flows of material and energy are environmentally compatible with nature. Preventive EMS strategies for technological innovation are viewed as central elements of the integrated environmental problem approach industrial ecology (as opposed to end-of-pipe, or downstream measures).

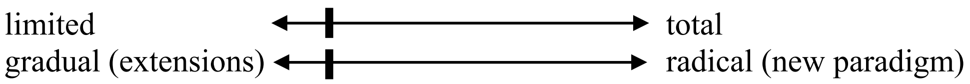
2.6.2. Key characteristics of the CEM understanding

The CEM understanding of industrial ecology include, in addition to the explicit standardised EMS such as ISO 14001 and the European Eco-Management and Auditing Scheme (EMAS), also other forms of environmental management. These other aspects include management systems such as Responsible Care, Corporate Social Responsibility (CSR) and the principles developed by The Natural Step to help organizations and communities understand and move towards sustainability. Firms' environmental reporting to its stakeholders is an important element of this understanding.

The understanding of industrial ecology as a framework for corporate environmental management can be characterized as focusing on *limited* changes to existing practices, by establishing corporate procedures, authority structures, targets and policies, rather than aiming for total transformations of industrial activity. The focus in this understanding is on continuous improvements in operations, largely by *gradual* extensions of existing practices, rather than a radical new paradigm that must be embraced.

The key formal characteristics of the CEM understanding of industrial ecology are summarised in *Figure 9*.

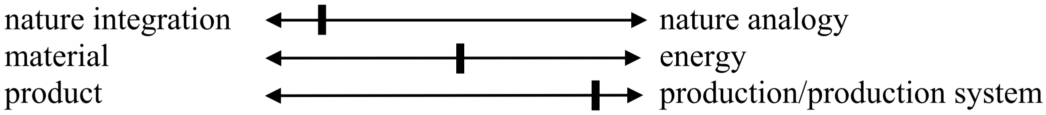
Figure 9 *Formal characteristics of the CEM understanding of industrial ecology*



The CEM understanding can be characterised by the substance element *nature integration* in that the focus is on reducing the environmental impacts of firms, thus improving the integration with the natural environment. This understanding has an emphasis on the management of *material* resources as well as *energy*. This understanding has a main focus on the *production* rather than the products. The production-focus is however usually limited to the manufacturing operations controlled by a single firm.

The key substance characteristics of the CEM understanding of industrial ecology are summarised in *Figure 10*.

Figure 10 *Substance characteristics of the CEM understanding of industrial ecology*



2.6.3. The actor-perspective in the CEM understanding

In the CEM-understanding of industrial ecology many types of actors have important roles. Corporations are the main actors in this understanding. Within the corporations important actors can come from the top management, middle management with responsibility for quality assurance and long-term planning, or individual employees contributing to the functioning of the management systems. Also governmental authorities can function as important actors connected to the mandatory requirement of some forms of quality management systems. This is the case with the internal control regulation, mandatory to all companies in Norway, which entered into forced in 1992. It is a quality management system aimed at demonstrating compliance with environmental, health and safety laws. The governmental agencies responsible for supervisory control to ensure that the enterprises comply with the internal control regulations are: Labour Inspection; Directorate for Fire and Explosion Prevention / Municipal Fire Board, Electricity Inspectorate, National Pollution Control Agency, Ministry of Children and Family - Section for Product Safety, and Local County Council.

Also connected to two other governmental regulations can governmental actors be important for the CEM understanding. Both the Norwegian Accounting Act and the Norwegian Limited Liability Companies Act require companies to publicly report on environmental aspects of their activities. These are laws, implying actor involvement of legislative and judiciary authorities.

2.6.4. Transport and the CEM understanding

Transport is not well included in the understanding of industrial ecology as a framework for corporate environmental management. Traditionally little attention has been paid to the implications of resource use connected to the companies' distribution systems (Paton, 1994).

Corporate environmental management has mainly been limited to production activities, while transport connected to the distribution of goods traditionally has been outside the responsibility of the producer. When corporate management adapts industrial ecology principles, the focus however changes somewhat, as pointed out by Allenby (1997). With life cycle assessment as an integrated element of corporate environmental management, the firms need to encourage the suppliers and distributors to implement proper HSE practices. Through this process of engaging suppliers and distributors could transport issues be included better in corporate environmental management.

The limited transport considerations in this understanding of industrial ecology are on the *efficiency* end of the *efficiency-pattern-volume* dimensional axis. These types of transport issues can be considered to be a part of the traditional understanding of HSE. The purification of polluting emissions by installation of catalytic converters and particle filters is a central element in the maintenance of distributors' and suppliers' vehicle fleets. Also the energy-efficiency of vehicles is in focus, mainly in the form of reducing the fuel consumption. The transition to alternative energies, another form of an *efficiency* approach, is also an option, although not commonly implemented.

Also the corporations' person transport is in question when industrial ecology is a framework for CEM. The relatively extensive character of industrial ecology in general implies that firms also must include the assessment of the environmental impacts from their employee transport. Both daily travels between the employees' homes and the workplace, business journeys, and the internal transport within the company are parts of the transport accounted for by a firm. But few corporations include this transport in their environmental management and reporting systems. The Norwegian company Telenor is one example of a company, which in addition to the *efficiency* problems, also bring in *pattern* problems through quite extensive reporting of the various modes used in transport by the employees of the company. This example may indicate that firms are beginning to offer incentives for switching to more energy efficient transport modes in employee travel. In this way the transport considered in this understanding of industrial ecology is also touching problems in the *pattern* segment of the *efficiency-pattern-volume* dimensional axis.

2.7. Industrial Ecology Type: Factor X

2.7.1. Central contributions to the factor X understanding

The Club of Rome report, *Factor Vier: Doppelter Wohlstand-halbierter Naturverbrauch* by Ernst von Weizsäcker, Amory Lovins and Hunter Lovins (1994), followed by the English version in 1997 *Doubling Wealth – Halving Resource Use* was important in spreading the factor X concept. A factor 4 of improvement in resource productivity is by the authors of this book envisioned to be near-term obtainable through already existing means. This is to be obtained in the areas of materials and energy use, including transportation. The many examples of improvements in resource efficiencies and in the use of energy range from issues as different as the "Hypercar" concept by Amory Lovins, to the production of low-energy beef. The examples of improvements in materials productivity cover issues ranging from sub-surface irrigation to electronic books.

In the contribution by Friedrich Schmidt-Bleek (1995) the factor 10 concept is connected to materials, and assumes that material turnovers should be reduced by at least 50% on a worldwide basis to avoid a systematic degradation of the biosphere. Since the per capita consumption is about five times higher in the OECD countries than in the developing countries, and the world population is increasing, Schmidt-Bleek claims that sustainable levels of material flows will not be reached unless and until the material intensity of the OECD countries is reduced by a factor of ten. The tenfold reduction of material flow per unit of service is to be realised over a period of 30-50 years, through a combination of technical, financial and lifestyle changes. Based on these considerations Schmidt-Bleek took the initiative to form the Factor 10 Club of environmentalists subscribing to that goal, formulated in the so-called Carnoules Declaration. The core industrial ecology principles of DFE and transition from linear to cyclical flows are essential elements in reaching a factor 10 of dematerialisation.

The study "Sustainable Germany" carried out by the Wuppertal Institute and Friends of the Earth resulted in the publication of the book "Greening the North: A Post-Industrial Blueprint for Ecology and Equity" by Wolfgang Sachs et al. (1998). This is a central contribution to the understanding of industrial ecology as being closely connected to the factor X concept. In the book industrial ecology is presented as a new paradigm that could contribute to a reduction in resource use.

Industrial ecology is here understood as an element of desired transformation to a sustainable society. It is conceived of as one possibility "founded on ideas and initiatives put forward, developed and implemented by ecologically aware people over the years". Sachs et al. consider industrial ecology as an important concept in a far-reaching conceptual framework for a process of fundamental societal transformation (ibid.).

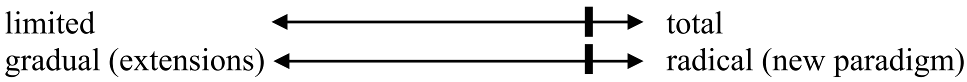
Lucas Reijnders brought the factor X debate into the industrial ecology literature through his contribution in the Journal of Industrial Ecology (Reijnders, 1998). Reijnders states that the factor X debate fits in a wider discussion on the importance of technological change in improving the environmental performance, and lowering the materials intensity of economies. The author claims that not much forcing of technologies aiming at a factor X with higher X-value exist, particularly in non-European countries. In using the indicators TMR (total material requirement) and MIPS (material input per service unit), Reijnders claims that factor X becomes a quantitative measure for the dematerialisation described in the industrial ecology contribution of Herman et al. (1989). Importantly, however, Reijnders points to that TMR and MIPS are not adequate environmental indicators, given the large differences in materials regarding their environmental impact. The environmental impact of an input into the economy of one tonne mercury is, for example quite different from the impact of one tonne alfalfa. Even so, Reijnders considers dematerialisation using the factor X concept a viable measure, but achievable only by strong government-driven policies, especially when X is large.

2.7.2. Key characteristics of the factor X understanding

The factor X understanding of industrial ecology can be characterised as aiming for *total* transformations of industrial activity, rather than limited changes to existing practices. The focus is on reducing the per capita material flows in the OECD countries as a whole. This understanding of industrial ecology is clearly a *radical new paradigm* rather than gradual extensions of current practices underway in industry.

The key formal characteristics of the factor X understanding of industrial ecology are summarised in *Figure 11*.

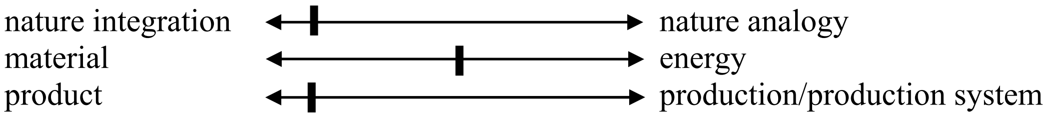
Figure 11 *Formal characteristics of the factor X understanding of industrial ecology*



The factor X understanding is clearly characterised by the substance element *nature integration* rather than the contrasting substance element nature analogy. The goal of the factor X dematerialisation is improved integration of industrial activities into the natural ecosystems. There is roughly equal weight on *energy* and *material* resources in this understanding. When considering the axis with the substance elements products and production/ production system, this understanding has a main focus on *products*. This is in the form of dematerialisation of products, achieved through the use of environmentally preferred materials, and substituting products by services.

The key substance characteristics of the factor X understanding of industrial ecology are summarised in *Figure 12*.

Figure 12 *Substance characteristics of the factor X understanding of industrial ecology*



2.7.3. Actors in the factor X understanding

In the factor X understanding of industrial ecology the actors are connected to changes in the form of technological innovations necessary to reach the goals of major resource productivity improvements. Reijnders (1998) points out that the resource productivity improvements of factor X, especially with high X-values, are achievable only with strong government-driven policies. Governmental actors thus become important for the implementation of changes in the factor X understanding of industrial ecology. Two strategies can be identified for governmentally induced forcing of factor X technology:

1) Technology-forcing law, as has been used for energy efficiency, for example in automobiles through the Corporate Average Fuel Economy (CAFE) regulations, requiring all vehicle manufacturers to comply with the fuel efficiency standards set by the U.S. Department of Transportation (Greene, 1990; Schipper and Meyers, 1992). Another example where technology-forcing law is used is in reducing automotive emissions of new cars (Ashford et al., 1985; Grant, 1995).

2) Using ecotaxation for increasing the attractiveness of factor X technology. This implies that environmental costs can be internalised through the taxation system. The ecotaxation strategy is strongly favoured by von Weizsäcker et al. (1997), who trace the roots back to the works by the British economist Arthur Cecil Pigou (1920). Pigou made the point that it would be good for the economy if fair prices were paid for common goods. Taxes would help adjusting the prices accordingly.

2.7.4. Transport and the factor X understanding

In the factor X understanding of industrial ecology transport is a central theme. Von Weizsäcker et al. (1997) give, in addition to the Hypercar concept, 10 examples of how the factor X principles are connected to improvements in transport. The examples cover videoconferences as substitutes for business travel, switching to low-transport-intensive products (yoghurt and local fruit juice as examples) and increasing the capacity and speed of both person- and goods rail transport. The public transport system of the Brazilian city of Curitiba, used by nearly 70% of the city's population, and initiatives for car-and city planning for car-free mobility are also given as examples. Through the large number of examples, the authors illustrate that it is possible to extract at least four times as much wealth from the energy and material resources we currently use in transport.

The transport theme of the Hypercar is an example of an *efficiency* theme, with main focus on new materials, giving lighter more energy-efficient cars, and alternative sources of energy.

However, *pattern and volume* themes can also be connected to the factor X-understanding of industrial ecology.

A *pattern*-transport theme encountered in the factor X understanding is the necessity of changing to *alternative modes of transport*. Goods transport on road will in this understanding to a large extent have to be replaced with the more energy-efficient transport by the modes rail and sea. The suggestions for achieving the desired modal change include disincentives for road-transport of goods, by charging systems reflecting the true external costs of this transport form (Sachs, et al., 1998, p. 90). Another pattern thematic addressed is the above-mentioned example of the public transport system in Curitiba.

Reduction in transport volumes is a transport problem, which can be associated with the higher X variants of factor X. There is a realisation in this understanding that the failure of reducing transport volumes severely restricts the possibilities of stretching the available energy resources. Sachs expresses policy aspects of the transport volume reduction problem as follows:

> Genuinely ecological transport policies primarily seek to influence the underlying conditions so as to attain step-by-step reductions of traffic volumes to an acceptable level. Avoidance of transportation is at the heart of ecological transition.
> (Sachs, 1998, p. 87)

2.8. Industrial Ecology Type: Resource analysis

2.8.1. Central contributions to the resource analysis understanding

The concept *industrial metabolism*, as described by Robert Ayres (1989), is the industrial analogy to nature's material metabolism. The work on industrial metabolism was based on earlier studies by the same author, on the connections between thermodynamics and economics (Ayres and Nair, 1984) and production, consumption, and externalities (Ayres and Kneese, 1969). Industrial metabolism denotes the transformation of materials and, to a lesser extent, energy in society. Ayres and his colleges built up the industrial metabolism concept from analyses of mineral and chemical mass balances (e.g. Ayres et al., 1985). They globalised the approach by comparing estimates of pre-industrial and contemporary human impacts on the nutrient cycles of carbon, nitrogen, sulphur and phosphorous (Ayres et al., 1994). As a background for improving resource use in the industrial systems, the contributions on industrial metabolism are central in this understanding of industrial ecology.

Robert Socolow et al. (1994) present mass-flow analysis, based on "total flow of materials" as a "unifying analysis" in industrial ecology. Mass-flow analysis is viewed as a "productive integrative tool", which "treats on a common footing all sources, all transport media, and all receptors". Within the understanding of industrial ecology as a tool for assessing material and energy throughput in society, it is commonly accepted that certain *reductions* are necessary in the future. The presence of suitable mechanisms are however required for a realization of a reduction in industrial use of materials and energy. Socolow et al. (1994) describe how, in various ways, such mechanisms are being developed in industry.

In their two recent contributions, Connelly and Coshland (2001a, 2001b) propose that a core deficiency in industrial ecology is "a rather weak definition of what constitutes resource consumption". They point to the fact that the industrial ecology literature only provides qualitative terms such as residuals, wastes, or pollution, to distinguish a consumed waste from the associated unconsumed feedstock. The authors however, define resource consumption as *exergy removal*. The process of allowing resource consumption to occur with decreasing levels of resource depletion is taking place through a process of de-linking consumption from depletion, through increased cascading, recycling, exergy efficiency, and renewed exergy use. This thermodynamic interpretation of ecosystem evolution provides a basis for quantitative analysis of strategies for reducing resource depletion. An indicator for resource depletion, the so-called "Depletion number", is introduced for expressing resource depletion per unit consumption. The authors also show how this methodology can be used in economic analysis to identify least-cost approaches to depletion avoidance in production and recycling of industrial chemicals.

2.8.2. Key characteristics of the resource analysis understanding

The understanding of industrial ecology as a framework for analysis of material and energy resources in industrial systems, cover both the flow of resources and the availability of materials and energy sources utilised in industrial production systems.

In this understanding it is claimed that we must learn from the biosphere and modify the industrial metabolism:

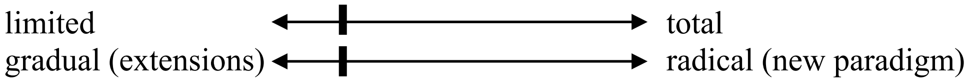
> "Modifications are needed both to increase reliance on regenerative (or sustainable) processes and to increase efficiency both in the production and in the use of by-products"
> (Ayres, 1989, p. 23)

The resource analysis thus aims at giving insights in how industrial metabolism can shift in the direction of increased efficiency in materials flow and waste streams. The foreseeable shifts in the industrial processes, resulting from the increased knowledge gained through resource analysis, are thus of a *limited* type, rather than in the form of total changes resulting from fundamental re-thinking and re-design.

This understanding is better characterised by the formal element *gradual* (extensions) than the contrasting concept radical changes (new paradigm). The knowledge generated by the resource analysis can give basis to many smaller changes in the industrial metabolism, but radical paradigmatic changes are not associated with this understanding.

The key formal characteristics of the resource analysis understanding of industrial ecology are summarised in *Figure 13*.

Figure 13 *Formal characteristics of the resource analysis understanding of industrial ecology*

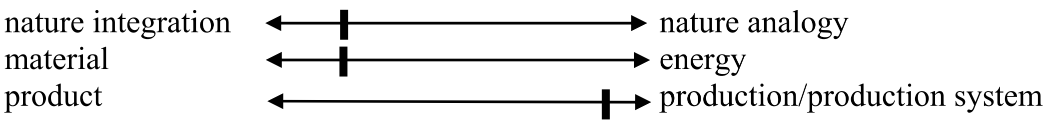


The industrial metabolism is an analogy to nature's metabolism. Thus the substance element nature analogy could immediately appear to be a more suitable characteristic than the contrasting element nature integration for this understanding. However the purpose of analysing the flow and stocks of resources in this understanding is to generate knowledge for better integrating industrial activities into the natural ecosystems. More optimal integration, based on the knowledge obtained through the analyses of the stocks and flows of resources, is at the heart of this industrial ecology understanding. *Nature integration* is thus used to characterise this understanding.

In this understanding there is more focus on *material* resources than on energy. Actually, rather few energy use analysis can be found in the literature representing this understanding of industrial ecology. This understanding has more focus on the flows through the industrial *production systems* than flows connected to individual industrial products.

The key substance characteristics of the resource analysis understanding of industrial ecology are summarised in *Figure 14*.

Figure 14 *Substance characteristics of the resource analysis understanding of industrial ecology*



2.8.3. Transport and the resource analysis understanding

In the understanding of industrial ecology as a framework for resource analysis, transport is not a main focus. It is quite rare to encounter transport themes within this segment of the industrial ecology literature.

Pertaining to those few transport issues that are considered within the industrial metabolism framework, a distinction is made by Socolow et al. (1994), who describes industrial metabolism as addressing "transportation", a wide concept referring to the "totality of civilization". The industrial ecology approaches represented by Graedel and Allenby (1995, 1998) however focus on narrower aspects such as the automobile, aircraft, petroleum, tire, battery, and other transport industries". Socolow thus points to the *efficiency* transport themes common in the industrial ecology literature. The "transportation" addressed in industrial metabolism, can be interpreted to include more of the *pattern* and *volume* segments of the efficiency-pattern-volume dimensional axis.

Resource limits for materials and energy systems for vehicles are examples of transport problems touched within the resource analysis understanding. The future limits of a sustainable industrial metabolism are characterised as being connected to the dynamic problems within industrial ecology (Andersson, 2001). Such dynamic problems include future energy systems for transportation. As discussed in Chapter 2.5.4, one of the most promising future energy conversion systems for automobiles is connected to fuel-cell technology. The operation of this system however is improved substantially in combination with an electric battery (hybrid electric/fuel cell). For electric batteries, several material flow studies have been conducted in industrial ecology (e.g. Socolow and Thomas, 1997a, 1997b). Many of the existing and potential battery types for automobiles contain metals that are toxic or have detrimental environmental effects. In the future, severe resource depletion of the metals needed in the production of these batteries might in addition emerge if large-scale systems were to be built. Cadmium, used in the production of nickel-cadmium (NiCd) batteries, is one example of a metal that could be mined to depletion with an extensive introduction of the fuel-cell technology (Andersson, 2001). As a response to the threats of resource scarcity, and also reflecting its toxicity, the EU recently started a process of phasing out nickel-cadmium batteries in new vehicles by banning their use from the year 2006 (EC, 2002b).

The problems connected to future energy systems for vehicles are examples of the transport themes of *alternative energy sources.* These are normally considered as efficiency themes. However, in the discussion of massive implementation of future energy systems for transportation, the *volume* problems are evident. It is thus justifiable to characterise the transport problem connected to the resource analysis understanding of industrial ecology as not being limited to *efficiency*, but also including elements of *pattern* and *volume*.

2.9. Comparison of the five types

In this chapter the different understandings of industrial ecology are compared according to their characteristics, identified in their individual presentations. First, the understandings are compared with respect to their characterisation by the formal elements.

The comparison of the understandings according to their characterisation by the formal elements *limited* and *total* is shown in *Figure 15*.

***Figure 15** Different understandings of industrial ecology characterised by the formal elements limited and total*

	Limited ←		→ *Total*
Product design	X		
Eco-park			X
CEM[18]	X		
Factor X		X	
Resource analysis	X		

As seen in *Figure 15,* three of the five understandings of industrial ecology are characterised as focusing on minor (limited) changes in existing systems. The understandings of industrial ecology as frameworks for product design, corporate environmental management and resource analysis are in this category. The eco-park and the factor X understandings of industrial ecology focus on larger (total) transformations of industrial activity, most evident in the eco-park understanding.

The comparison of the understandings according to their characterisation by the formal elements *gradual (extensions)* and *radical (new paradigm)* is shown in *Figure 16*.

***Figure 16** Different understandings of industrial ecology characterised by the formal elements gradual (extensions) and radical (new paradigm)*

	Gradual (extensions) ←	→ *Radical (new paradigm)*
Product design	X	
Eco-park	X	
CEM	X	
Factor X		X
Resource analysis	X	

As is shown in *Figure 16*, four of the five understandings of industrial ecology are characterised as focusing on gradual changes (extensions) to existing systems. The only understanding of industrial ecology that is characterised as radical and constituting a new paradigm is the factor X understanding.

The different understandings of industrial ecology are also compared with respect to their characterisation by substance elements. The comparison according to their characterisation by the substance elements *nature integration* and *nature analogy* is shown in *Figure 17*.

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Figure 17 *Different understandings of industrial ecology characterised by the substance elements nature integration and nature analogy*

	Nature integration ⟷	*Nature analogy*
Product design	X	
Eco-park		X
CEM	X	
Factor X	X	
Resource analysis	X	

As illustrated in *Figure 17*, four of the five understandings of industrial ecology have focus on improving the integration of industrial systems into nature. The only understanding of industrial ecology in which the analogy to nature is predominant is the eco-park understanding.

The comparison of the different understandings of industrial ecology according to their characterisation by the substance elements *material* and *energy* is shown in *Figure 18*.

Figure 18 *Different understandings of industrial ecology characterised by the substance elements material and energy*

	Material ⟷		*Energy*
Product design	X		
Eco-park	X		
CEM		X	
Factor X		X	
Resource analysis	X		

In *Figure 18* it is clear that three of the five understandings of industrial ecology have a higher focus on material considerations than on energy issues. Only the factor X and the CEM understandings have about equal focus on energy and material.

The comparison of the different understandings of industrial ecology according to their characterisation by the substance elements *product* and *production/production system* is shown in *Figure 19*.

***Figure 19** Different understandings of industrial ecology characterised by the substance elements product and production/production system*

	Product	*Production/production system*
Product design	X	
Eco-park		X
CEM		X
Factor X	X	
Resource analysis		X

As is illustrated in *Figure 19*, in three of the five understandings of industrial ecology the focus is mainly on issues connected to *production* and *production systems*. The two understandings of industrial ecology with a main focus on *products* are the product-design and the factor X understanding.

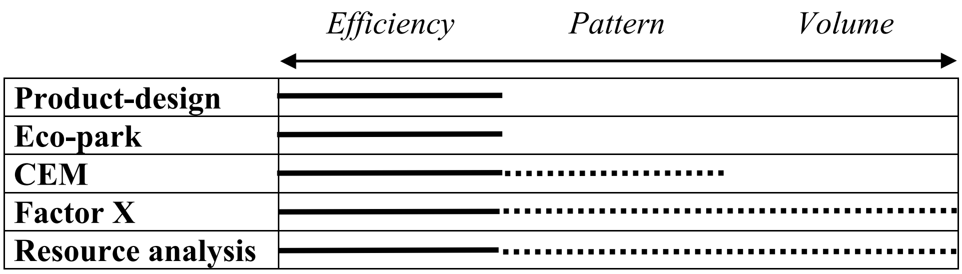
2.10. Comparison of transport in the types

In this sub-chapter the different understandings of industrial ecology are compared with regards to their inclusion of transport themes. The comparison is based on the characterisation of the transport themes in the three dimensions *efficiency, pattern and volume*. This is followed by a more extensive discussion of transport issues connected to each of the understandings. This includes examples of efficiency, pattern and volume transport themes, and a discussion of their inclusion in the different understandings. This is carried out by first a discussion pertaining to the two main forms of transport; *person* and *goods* transport, followed transport in general. At the end of the sub-chapter are some conclusions made on the discussion of transport in the various understandings of industrial ecology.

2.10.1. Characterisation of transport questions in the five types by the dimensional axis efficiency, pattern and volume

Figure 20 illustrates the characterisation of the transport themes in the five types of industrial ecology understandings by the dimensional axis *efficiency, pattern and volume*. In the understandings with transport themes covering more than one dimension, the minor focus is shown with dotted line.

***Figure 20** Transport themes in the five types characterised along the dimensional axis efficiency - pattern - volume*



As shown in *Figure 20*, two of the five understandings of industrial ecology are limited to *efficiency* themes. The product-design and the eco-park understandings are only suited for dealing with themes connected to the efficiency of transport. The CEM understanding also includes *pattern* themes, but this is not as dominating as the efficiency themes. Transport issues in the factor X and the resource analysis understanding in addition include some thematics connected to volume themes.

2.10.2. Final discussion of person transport in the types

Person transport is not immediately associated with industrial ecology. Transport in connection with industrial ecology is traditionally understood as the movement of goods to, from and between industrial facilities. Raw material must be transported to the production facilities, and finished products must be transported to the customers. In addition there is internal transport and transport of waste and by-products.

The private car is however a product dealt with extensively in industrial ecology. The design and production of vehicles for *person* transport (mainly automobiles) is particularly well included in the product-design and the factor X understanding. The claims of dematerialisation in the design and production of new automobiles are thus examples of problems connected to person transport.

In the product-design understanding of industrial ecology rather optimistic claims of dematerialisation are frequently being made. One example of a commonly encountered efficiency issue is the design of new automobiles, using lighter materials resulting in reduced fuel consumption. The previously mentioned 12% reduction in fuel consumption from 1980 to 1990 of the average new automobile in the USA is used as an example of dematerialisation (Keoleian et al., 1997, p. 56). This however only tells part of the story. The dematerialisation claim fails to recognise the more recent increase in the direction of heavier average cars with stronger engines and higher fuel consumption. Empirical data on the fuel consumption of average new cars indicate no significant decrease in the more recent years. The fuel consumption per 100 km of an average new UK automobile in 1987 was 7.92 litre, while in 2000 it was 7.91, for example (UKDOT, 2001). When taken into consideration that the average occupancy rates of private cars has been reduced in the same period of years, it is even less basis to the claimed argument of increased fuel efficiency of the private automobile, expressed as fuel consumption per person-kilometres, a common unit for fuel efficiency used in a societal context. The average occupancy rate, expressed as the number of persons per car, in Norway is reduced from 1.86 to 1.77 in the period 1987-2000 (Rideng, 2001).

If indeed lighter automobiles can be considered a form of “dematerialisation”, this is however connected with serious problems. Lighter automobiles can contribute to major problems regarding the *transportation safety* for both drivers and passengers. The use of the private car is a major source of deaths and disabilities from transport activities. Approx. 25 000 persons in automobiles are killed in the

EU15 every year. The drop in the average weight of passenger cars, such as the development between 1975 and 1985 in the USA, made the cars less safe for the driver and the passengers. A study has indicated that a driver of a 1000-kg car is 2.6 times more likely to be killed in a single car collision than when driving a 2000-kg car (Herman et al., 1989, p. 51). Lighter cars are thus less safe both for the driver and the passengers.

Also other problems emerge with the understanding that replacing heavier materials with lighter materials in private cars is a form of dematerialisation, particularly regarding the large replacement *volumes* in question. The replacement might actually in some respects imply environmental degradation. Substitution of steel in automobiles with the lighter material *aluminium* is one example where this could be the result. The following should illustrate this point. Aluminium is produced from bauxite in a two-step process that refines the bauxite into aluminium oxide (Bayer process) and then reduces the aluminium oxide (Hall-Heroult electrolysis) to aluminium metal. The mining of bauxite and refining into aluminium oxide are two far from environmentally benign processes. The key step in the refining of bauxite involves the removal of silica under heat and high pressure. This results in waste in the form of a red mud that drastically reduces soil fertility (Bunker, 1994). The red mud contains in addition *heavy metals*.

As will be dealt with in the sub-chapter on goods transport, bauxite and aluminium are in addition transported globally and in increasing amounts, as is shown in *Table 4*.

The substitution of aluminium for steel in private cars also might contribute to environmental problems in the form of emissions of polluting gases to the air. The smelting of aluminium oxide to form aluminium metal is an electrolytic reaction where electric current is passed through a fluoride bath. This process contributes to *particulate emissions* in the form of aluminium oxide dust, carbon dust and fluoride compounds. The gaseous emissions include HF, CF_4, C_2F_6, other fluoride-bearing gases, CO_2, CO, and SO_2. Significant amounts of fluorocarbons are emitted at rates of 1.5 to 2.5 kg per tonnes of aluminium produced. These fluorocarbons are *potent greenhouse gases*, with global warming potentials of many thousand relative to CO_2. The global warming potentials for CF_4 and C_2F_6 are 5 700 and 11 900 respectively (IPPC, 2001). These two compounds are also among some of the most stable industrial pollutants known, with lifetimes of 50 000 and 10 000 years respectively (ibid.). The emission of the fluoride-containing gases has historically been reduced by improved control routines during the process, and some never aluminium plants, also capture and recycle most of the fluoride-containing emissions (Bunker, 1994, p. 443). The fluorocarbons emitted from the aluminium production could however still account for as much as 1,7% of total human greenhouse gas releases (Keoleian et al., 1997, p. 27).

The production of aluminium is in addition much more *energy intensive* compared to steel, as is clear from *Table 1*.

***Table 1** Energy use in production of aluminium and steel (kWh/tonne)*

Process stage	Aluminium	Steel
Mining	1 668	1 711
Ore Preparation	8 507	922
Smelting	35 384	6 055
Casting and Finishing	4 937	2 452

Source: Keoleian et al. (1997, p. 29)

It is only in the mining process stage that the energy use for aluminium is similar to steel. Ore preparation is more than nine times, smelting close to six times, and casting and finishing two times more energy intensive for aluminium than for steel production. The high energy use for the smelting of aluminium oxide to form aluminium is due to the particularly strong chemical bonds to oxygen in this metal, bonds that are broken by applying electricity at high temperatures.

Substitution of automobile parts with the lighter material *plastic* is another example, which, particularly in the product-design- understanding, is claimed to represent a form of dematerialisation. As with the case for aluminium, this replacement is not necessary leading to less environmental problems, particularly when considering the large replacement volumes in question. First of all, the production of plastic materials is highly dependent on continued exploitation of *fossil fuels supplies.* The alternative of using recycled plastic is only to a small degree possible. The complexity of different forms of plastic is a major problem for the production of plastics based on recycled material. The large replacement volumes in question pose serious *recycling and disposal problems* (Frosch, 1995). The automobile contains approximately 25 chemically incompatible forms of plastics, which cannot be melted together and reused (Keoleian, 1997). The individual forms of plastic must be separated before recycling, a task requiring large inputs of energy and material resources connected to construction and operation of facilities and equipment. The solution is often to incinerate remaining plastic material for energy recovery, which is a far from environmentally benign solution. Chlorine-containing plastics such as PVC are known *sources of dioxin emissions* when incinerated. But also other plastics can produce dioxins when burned in the presence of chlorine donors such as road salt, which is commonly trapped in the automobile bodies during the use phase. The result is that most of the plastic from retired automobiles currently are disposed in landfills (ibid.). The "dematerialisation" by replacing steel with plastic in automobiles might thus actually imply an escalation of environmental problems connected to incineration and land-filling.

The use of the lighter materials plastic and aluminium instead of steel in private cars can be described as a form of *re-materialisation* instead of dematerialisation. Re-materialisation is a term used for describing the use of new materials in the process of commodity production (Mofatt et al., 2001). This is rather different from the dematerialisation claimed to be necessary for sustainability, as interpreted in the product-design and factor X understandings of industrial ecology.

Changes to the private car also can have other important implications for transportation. Changes in the design and functioning of automobiles have led to reduced emissions of some polluting compounds. The introduction of the 3-way catalytic converter in automobiles has reduced the amount of NO_x, HC and CO emitted from each vehicle, per kilometre driven. But the increased use of the catalysts has also in itself created other environmental problems. The catalysts are based on the *Platinum*-group metals, which are only found in scarce deposits in nature. Ores of platinum in as low concentration as 7 ppm are currently being mined. Frosch and Gallopoulos (1989, p. 99) point to that about 20 million metric tonnes of ore must be refined to produce the approx. 140 tonnes purified platinum metal for the USA market per year. More than 40% of this is used in automobiles (Keoleian et al., 1997, p. 22). The mining of platinum involves encroachment into large areas of land, movement of large volumes of earth and leaves behind millions of tonnes polluted tailings and polluted surface and ground water (Høyer, 1997, p. 820).

The use of platinum in catalytic converters can also represent problems with relevance for the eco-park understanding of industrial ecology. Recycling of platinum is, to a large extent, not carried out, and the problems concerning the disposal of this material are escalating (Frosch and Gallopoulos, 1989, p. 99).

The changes in the products focused within the product design and factor X understandings of industrial ecology aim at developing products with improved environmental performance. The new products are however not necessarily reducing the severity of environmental problems, but sometimes rather contributing to other forms of ecological disturbances. This is the case with the replacement of chlorofluorocarbon (CFC) gases in automobile air conditioners. The most widely used replacement chemicals are extremely potent greenhouse gases. The most common replacement for CFCs used in automobile air-conditioners is HFC-134a, which was introduced in new vehicles in 1993. This compound has a global warming potential of 1 300 times that of CO_2 (IPPC, 2001). This is thus another example particularly connected to the design understanding of industrial ecology, where a problem “solved” by a technical product change rather ends up creating other types of problems. The technical “solution” has contributed to the amplification of another problem, the increased emission of greenhouse gases.

Another problem connected to the product-design understanding of industrial ecology is the limit connected to DFE. Sometimes the system limits in DFE are narrowly defined, focusing on small parts of the design of the products. This can increase the risk that industry can be enmeshed in complicated tradeoffs regarding small aspects of complicated products. This again can cause the manufacturers to miss entirely the need for more fundamental changes in broader system structures. An example can be taken from the automobile manufacturing industry: A team of automotive engineers can be discussing the environmental aspects of using plastic versus aluminium radiator caps, while more fundamental questions about the sustainability of the petrol powered automobile are never raised. Although smaller changes in products and process designs are necessary, this focus on minute changes implies a risk of “loosing sight of the forest for the trees” (O’Rourke, 1996). This example illustrates the limitation of industrial ecology understandings that focus mainly on *efficiency* aspects of transport problems.

The issue of *moderation in time and space* is connected to the reduction in transport volumes (Sachs, 1998). Slower speeds and shorter transport distances are central components of this problem. It is usually a fact that higher speeds lead to saving time, but the history of transportation shows that the gains quickly are offset by increased amount of transport. The *constant travel time principle* of transport implies that a reduction in travel time by 10%, for example, is compensated by a similar increase in travel time from longer distances or increased frequency. A slower speed also has implications connected to the possibilities for stretching the available energy resources. The connection between speed and increase in a vehicle's energy throughput is not at all linear. The energy use goes up exponentially due to increased resistance and friction. A car using 5 litres of fuel per 100 km at 80 km/h, will not need 10, but 20 litres of fuel per 100 km at 160 km/h. A reduction in energy use by a factor of 10 is thus difficult to comprehend without taking into consideration a reduction of maximum speed of vehicles, while simultaneously striving for more efficient motors and new materials (ibid. p. 88).

The pattern of person transport has changed in recent years to less use of energy efficient transport modes. The mode changes have consisted of more use of automobile and aeroplane, and less use of rail transport. Rail is by far the most energy efficient transport mode for person transport, while aviation and high-speed sea transport are the least energy efficient (Høyer & Heiberg, 1993; Høyer et al., 1998; EC, 2001). This pattern change is contributing to the increasing global energy use for transport, up by 48% between 1980 and 1998 (EC, 2002a).

A factor 10 of dematerialisation implies that material input per service unit (MIPS) in the OECD countries should be reduced by a factor of ten to reduce the global material turnover by one-half within one generation. It is hard to imagine that such a degree of dematerialisation is obtainable. Particularly in the field of transport is it difficult to envisage how a world with twice today's population can obtain this. It does not appear likely that further increase in the automobile-based person mobility towards the levels of current OECD-average is compatible with a 50% reduction in the global use of material resources. Establishing the required transport infrastructure alone would generate an increase of factor 10 in the use of material resources for such purposes (Høyer, 1997, p. 819). It is not likely that increased recycling, waste reduction in production, increased energy efficiency, and extension of the lifetime of products are sufficient to obtain a factor of 10 of dematerialisation. A dematerialisation by a factor of 10 does not appear to be compatible with an increased number of private cars and increased person transport volumes. The need for volume-reductions becomes evident.

2.10.3. Final discussion of goods transport in the types

The efficiency improvements in goods transport have only resulted in small improvements in the overall energy efficiency of this form of transport. In fact, there has been no improvement in the overall energy efficiency of road-based goods transport in the EU the last two decades, partly due to a lowering of *load factors* (EEA, 2001, p. 39). This is illustrative of the shortcomings of those understandings of industrial ecology that are limited to efficiency themes. This is the case for the product design and the eco-park understandings.

The understanding of industrial ecology as a framework for corporate environmental management also has major limits for dealing with transport themes. One limitation connected to the standardised EMS, such as ISO 14001 and EMAS, is the traditional focus on the production activities in this understanding. The transport connected to the distribution of the final products to the customers in most cases is outside the control of the producers. The outsourcing of transport services to contractors is a contributing factor to the lack of control by the producers. Even though an EMS specifies that contractor audits are required, it is evident that the outsourcing weakens the producer's responsibilities for the environmental impacts of these transport activities.

Also in goods transport there has been a change the recent years in the pattern of the transport. There has been a change to relatively less use of energy efficient transport. Such *mode changes* have consisted of increased use of aeroplane and lorries, and relatively less use of goods transport on rail and sea. Rail is a much more energy efficient transport mode than road for goods transport, while aviation is the least energy efficient (EC, 2001). Sea transport is the most energy efficient mode for transport of large volumes of goods over long distances.

The necessary changes in the modal composition of good transport, such as those prescribed in the factor X understanding, might be connected with major problems. Particularly the transfer to a future of more reliance on high-speed trains can be problematic for transport of goods by rail. High-speed person transport by rail often has higher priority than goods transport, slowing down the goods transport. This could make the rail mode less attractive for goods transport. A *reduction* of both person and goods mobility, might thus be necessary for dealing with these problems in the future.

A limit for the inclusion of volume themes particularly in the product design understanding, and also to a certain extent in the eco-park understanding, is connected to the view on industrial dematerialisation in these understandings. Two questions connected to this can be asked:

1) Has dematerialisation occurred in transport?
2) What are the conditions for further dematerialisation in transport?

Tibbs' example is representative for the product-design understanding's interpretation of dematerialisation:

> "In industrially developed economies, dematerialisation – a decline in materials and energy intensity in industrial production – is an established trend. When measured in terms of physical quantity per constant dollar of GNP, basic materials use has been falling since the seventies, and has even levelled off when measured in terms of quantity consumed per capita. Practical examples of this trend are the steadily declining size and increasing power of computers, or the nearly 20 percent drop in the average weight of automobiles in the USA between 1975 and 1985. And micro-structural engineering of smart materials is yielding even lighter, higher-performance components."
> (Tibbs, 1992, p. 13)

This view on dematerialisation however fails to recognize that the absolute volume of consumed material, rather than the volume relative to GNP, is a more significant measure of dematerialisation in ecological terms. This view can in addition be characterised as representing a limited understanding of dematerialisation regarding the range of minerals used and the physical and chemical processes involved in their extraction (Bunker, 1996). The dematerialisation claims by Tibbs do not address the fact that, on a global scale, the volumes and distances transported of major minerals have increased over the periods for which dematerialisation has been claimed. This is partially due to the fact that extraction and processing of main minerals have expanded greatly in scale. This is shown for crude oil in *Table 2* and bauxite and alumina in *Table 3*.

Table 2 *World production of crude oil (in million barrels per day, and factor increase since 1960)*

Year	**Produced volume**	*Increase from 1960 (factor)*
1960	21.0	*1.0*
1980	59.6	*2.8*
1999	65.9	*3.1*

Source: USDOE (2000)

The increase in global extraction and processing of bauxite and alumina is shown in Table 3.

Table 3 *World production of bauxite and alumina (in 1000 tonnes, and factor increase since 1960)*

Year	**Produced volume**	*Increase from 1960 (factor)*
1960	27 641	*1.0*
1980	89 220	*3.2*
2000	127 000	*4.6*

Source: USGS (2002), Mbendi (2002)

In addition to increase in the extraction and production of crude oil, bauxite and alumina, the world production of iron ore has increased from 864 million tonnes in 1986 to 938 million tonnes in 2000 (USGS, 2002). The production of coal has increased from 3.7 million tonnes in 1980 to 4.3 million tonnes in 1999 (USDOE, 2000). Extraction and processing of major minerals also have moved into more and more remote locations to compensate for increased consumption and depletion of deposits close to existing industrial centres (Bunker, 1996). This has resulted in a situation today, where the major minerals are transported vastly more now they were four decades ago, as illustrated by the seaborne transport shown in *Table 4*.

Table 4 *Transport volume of sea-borne raw materials 1960-1999 (in billions tonne-km, and factor increase from 1960)*

Year	**Crude oil**	*Factor in-crease from 1960*	**Coal**	*Factor in-crease from 1960*	**Iron ore**	*Factor in-crease from 1960*	**Bauxite and alumina**[19]	*Factor in-crease from 1960*
1960	2 655	*1.0*	233	*1.0*	425	*1.0*	55	*1.0*
1980	11 574	*4.4*	1 540	*6.6*	2 656	*6.3*	277	*5.1*
1999	12 832	*4.8*	3 781	*16.2*	3 728	*8.8*	328	*6.0*

Source: Bunker (1996), Fearnleys (2000).

The production volumes of crude oil increased by a factor of 3.1 between 1960 and 1999 (*Table 2*). The volume of sea transport of the same raw material however increased by a factor of 4.8 (*Table 4*) over the same time period, indicating that each barrel of oil on the average is transported 55% longer in 1999 than in 1960. The same development is evident for bauxite and alumina for which the production volume has increased by a factor of 4.6 (*Table 3*) while the transport volume has increased by a factor of 6.0 (*Table 4*) in the same period of years, indicating an average increase of 30% in the transported distance for each tonne of this group of raw materials. The increases in the transport volumes of coal and iron ore have been even stronger, with factors of 16.2 and 8.8 respectively (*Table 4*), but reliable data on production volumes for the entire period is not available, limiting the basis for similar conclusions on transport increase per unit of these two minerals.

The combination of increased volumes of raw materials and its accelerating transport around the world sharply contrasts the dematerialisation claims frequently encountered in the product-design understanding of industrial ecology. The fact that dematerialisation not appears to have a major effect in reducing the consumption of raw materials is thus outside the product-design understanding of industrial ecology.

A barrier for the inclusion of transport volume themes in several understandings of industrial ecology is connected to the *limited view on nature's complexity*, common in these understandings (O'Rourke et al., 1996). In the product-design, eco-park and the CEM understandings improved design and control are key solutions to the environmental problems. This view may however reduce the problems to merely technical and manageable aspects. One example is the claim by Tibbs (1992, p. 10) that ecological damage can be avoided by stressing design that is "intrinsically incapable of acute environmental impact". This way of managing the interface between industry and nature by utilizing "ecofeedback" strategies is overly optimistic. It is based on a rather limited view of nature's complexity. The idea of using "real-time" information about environmental conditions is an exaggeration of current monitoring capabilities, which cannot always predict the consequences of today's emissions and encroachments on tomorrow's ecosystems (O'Rourke et al., 1996). These types of problems have long feedback loops, which mean that uncertainty is often connected with the

[19] Data for 1980 are not available. The figure of 277 billion tonne-km is for the year 1981.

effects on the ecosystems. The destruction of the ozone layer resulting from CFC emissions, and climate change from greenhouse gas emissions, are illustrative examples of such problems. CFCs were released from industry and consumer products 1930s to 1970 at steadily increasing amounts (except during years of the recession and World War II) without any apparent environmental damage. A high degree of uncertainty was however connected with the long-term effects on the ecosystems, from the release of these compounds. This uncertainty was the basis for the actions implemented to limit the production and use of these industrial substances. The effect on the stratospheric ozone layer was not seen until later. The anthropogenic emissions of greenhouse gases, mainly resulting from the burning of fossil fuels, also have taken place at increasing rates during the last century. The uncertainty regarding the effects on the global ecosystems, in the form of climate changes, is being applied in efforts to reduce these emissions. The limited view on nature's complexity is thus a barrier to the inclusion of transport problems that have uncertainty connected to their ecological effects.

The societal processes for volume *reduction* require comprehensive approaches, reflecting the fact that it is the sum of all the individual automobiles, aeroplanes, and lorries etc., which contribute to the major environmental problems, such as climate changes due to the increased emission of greenhouse gases. The limited view of nature's complexity tends to reduce the environmental problems to merely solvable by technical efforts. The climate changes are thus understood as being "solved" by improved design and control solutions, not considering the systemic changes necessary for obtaining necessary reductions of global goods mobility.

A more principal aspect of ecological disturbances caused by the *high volumes of transport* is that these problems are generated through product consumption and distribution chains. An efficiency-oriented design approach is not optimal for solving such environmental problems of a systemic character. An encroachment today can in some cases give a full backlash not until after hundred years, even if, in the meantime, the extent of the encroachment is reduced. The long feedback loops, with their uncertain time lags and cause-effect relations, are much less prone to solutions by technical efficiency design approaches than the more easily defined short feedback loops. It is in addition much easier to develop and implement technical solutions when the sources are a few, concentrated and well-defined points, than when they are many, scattered and diffuse, which is the case for transport. A more suitable approach to such problems is that of seeking solutions by input management, which means in addition to increasing the efficiency of production systems, also reducing the inputs of environmentally damaging materials (Odum, 1989). This is an approach which is more compatible with the factor X understanding than the other understandings of industrial ecology.

The problems connected to the increase in *transport volumes* resulting from increased goods- mobility and the connected *increase in transport infrastructure* is outside the scope of the EMS understanding of industrial ecology. There is a clear limit for corporate environmental management in handling these more systemic transport problems. The corporations are dependent on making profits from selling their products and services. The corporate stimulation of reduction in transport connected to these activities is however difficult to envisage.[20] For transport companies, which are based on providing transport services, the establishing of environmental management systems is mainly limited to having an effect on transport themes of the *efficiency* type. Major reduction in transport is not compatible with the management interests in these companies.

One of the limits of the eco-park understanding is conceivable through the concept "zero" emission industrial clusters. This concept is based on the natural ecosystem analogy, where waste from one industrial process is used as raw material for another process. The waste-donors and the waste-receptors are located in close proximity, in co-called industrial clusters, to minimise the necessary transport. The immediate objection is that the emissions from the total cluster never can be zero. In theory it is possible to imagine that one of the facilities could get all its raw materials in the form of waste from the other facilities in the cluster. Correspondingly, it could be possible that this facility could obtain its energy needed from excess energy from the other facilities in the cluster. The emissions from the transport of material and energy into the individual industrial facilities in the "zero-emission" cluster also theoretically could be close to zero, due to minimal transport distances within the cluster. It is however not possible that all the facilities making up the industrial cluster are in such a favoured situation, that they obtain all their energy- and material needs through recycling within the cluster. Neither can all wastes be utilised. In addition, the total industrial cluster must be supplied with energy and raw material from the outside. Even though it is theoretically possible that the supplied energy and raw material are recycled from another cluster, the energy use and emissions from the transport can never be zero. One objection to this is that the energy could be based on renewable, so-called "non-polluting" technologies. It is however a problem that there are no energy-technologies that are not polluting in a life-cycle perspective. Even hydropower, sun-, bio- wind- or wave-energy implies environmental encroachments, for example, in the form of installations disturbing natural ecosystems. In addition, these technologies require production and maintenance of equipment and infrastructure that can utilise these energy forms. This production and maintenance can never be carried out without causing pollution.

The closing of material cycles is an important principle in the eco-park understanding. A weakness in the "loop-closing" theory is that it is commonly overlooked that degraded materials (waste) must be regenerated, and usually *transported*, before they can be recycled (Connelly and Coshland, 1997). The eco-park understanding focuses on one main strategy for resource conservation: recycling. Other strategies for reducing the depletion of resources, such as *increased renewable energy* use and *increased energy efficiency* receive far less attention. This understanding thus provides limited solutions to the problems connected with the increase in fossil fuel consumption from the increasingly larger volumes of goods transport.

In the eco-park understanding there is a focus of *trading waste* and even *designing waste* that can be utilized by other industrial facilities. This might represent a

[20] The selling of services instead of products is however a strategy often connected to the factor X understanding of industrial ecology.

conflict with a principle of source reduction of pollution. Source reductions are based on avoiding waste-generation in the first place, and thereby reduce the need for transport of waste material. This delimits the eco-park understanding of industrial ecology from clean production activities, in which principles of source reduction are well established. Clean production has actually been described as the European equivalent of pollution prevention in the United States (Ashford, 2002). Pollution prevention and source reduction are closely related concepts. The difference between industrial ecology and clean production, according to Karamanos is (1995, p. 38):

> "Cleaner production focuses on waste reduction, while in industrial ecology the emphasis is on cycling of unavoidably produced wastes, especially between companies"

The potential avoidance of waste-reduction, because the waste can be traded, can thus represent a limit for the eco-park understanding of industrial ecology. More complex approaches are required to simultaneously take into consideration source reduction of pollution, waste minimisation and the utilisation of residues. Otherwise the result might be even more transport of waste.

The problem of increased *transport volumes* connected to recycling systems is not often addressed in the industrial ecology literature. This is problematic as many studies show that transport volumes can be quite immense in connection with systems for reuse and recycling. One example is used by Leach et al. (1997) in the systems for paper recycling in UK. In some of these recycling systems a massive energy use is documented, mostly resulting from the transport to the recycling plants. At one case plant which has been studied, the Aylesford Newsprint recycling mill in Kent, 30 000 deliveries of waste paper per year was received by lorry, constituting a total annual transport distance of more than 4 million kilometres. This results in more than 5 800 tonnes of CO_2 emissions per year. In addition come the journeys made by individual recyclers from their homes to the neighbourhood recycling bins. One study referred to in rural Norfolk found that cars travelled 270 kilometres for every tonne of waste delivered in local bins (ibid.). The long transport distances to recycling plants, plus the transport necessary to distribute the recovered materials, can thus generate large transport volumes, usually not considered in the eco-park understanding of industrial ecology.

2.10.4. Final discussion of transport in general in the types

Many transport problems cannot be considered to be unique for either person transport or goods transport. A discussion of these type of problems connected to transport must also be discussed in light of the various understandings of industrial ecology.

The eco-park understanding has clear limits for inclusion of transport problems in general. The first is the limit in scale. The natural ecosystem analogy is usually limited to individual eco-industrial parks. The wider industrial production systems, and the transport between them, are considered only to a much lesser extent.

The eco-park understanding of industrial ecology also implies that near-closed material cycles corresponding to those found in natural ecosystems should be established. Expanding systems of waste exchanges through the creation of so-called industrial ecosystems or eco-industrial parks are practical examples of efforts to close the loops. The most often cited example of industrial ecosystem is the so-called *industrial symbiosis* complex in Kalundborg, Denmark (Knight, 1993; Karamanos, 1995; Edgington, 1995; Lowe et al., 1997b). Two of the core facilities in this industrial cluster are however based on the exploitation of non-renewable resources. With both a coal-fuelled power plant and a petroleum oil refinery making up the core of the complex, it is quite misleading to use the term industrial ecosystem for this industrial complex. The analogy to nature's ecosystems is in this case limited to waste exchanges, and fails to include the wider transport problems connected to the main operations. The petroleum oil refinery is for example a part of the production chain for a non-renewable fuel source for transport.

Another limit for the eco-park understanding is connected to the sources of emissions in the industrial ecosystems. In establishing or maintaining "zero"-emission industrial clusters, the focus is on reducing the waste from industrial facilities. These sources are the traditional point sources of emissions from industrial production. In this focus on the point sources, the increasingly more important diffuse sources are not well addressed. By reducing the point sources, the pollution is still coming out of the factories, not through the factory chimney, but through the factory doors, in the form of the products being produced. The example of polluting automobiles being produced by "non-polluting" factories is illustrative of this situation. This limited focus on the diffuse sources of emissions from the distribution and use of the industrial products is a main deficiency of the eco-park understanding. Reducing the diffuse sources of emissions, of which transport is an important element of, require more complex approaches then represented through the eco-park analogy understanding.

It is also possible to point to important limits for the inclusion of transport in general for the CEM understanding. The increases in *transport volumes* are results of globalisation processes outside the normal control of corporations through their management systems. However, with the concepts connected to the wider implications of corporate activities, such as Corporate Social Responsibility (CSR), potential possibilities for including more systemic transport problems emerge. CSR refers to the overall relationship of a firm and all its stakeholders, and could be an important factor in this context. Public concerns regarding the social accountability of corporations and their *operations in the global marketplace* have led to the forming of guidelines in this field. Even though the guidelines not explicitly address reduction of transport volumes, this aspect certainly has relevance when discussing the improvements of social issues. High volumes of transport have detrimental social effects, for example in the form of traffic accidents, which have serious social consequences and are in addition expensive for society as a whole. People die or become injured and disabled, resulting in wide and lasting social impacts on their families.

Energy for transport is a theme that has low focus in most of the industrial ecology understandings. O'Rourke et al. (1996, p. 105) also point to the general lack of energy considerations in the industrial ecology literature. The failure to address energy issues is thus a weakness for the inclusion of transport issues, since they are tightly connected to energy use. The alternatives to fossil fuels are ranked as the number one problem facing industrial ecology (ibid.). "The failure to address the use of fossil fuels reflects the large weakness in industrial ecology's handling of energy issues". Major problems connected to transport's increasingly important role as a consumer of fossil energy, is thus emerging from the failure of addressing these issues in the various understandings of industrial ecology. As discussed previously (in Chapter 2.9), only the factor X and the CEM understandings have a reasonable inclusion of energy considerations.

Improved understanding of the limits of industrial ecology could also be gained by applying the concept of *exergy* in material and energy considerations (Connelly and Coshland, 1997; Wall, 1986). Exergy considerations are however not common in the industrial ecology literature. Failure to apply such analyses could halt the establishing of energy-efficient material recycling and utilisation of renewable sources for energy in industrial systems. This is again of particularly relevance in the discussion of transport problems. Avoidance of transferring to renewable sources of energy for transport makes, for example significant reductions in greenhouse emissions from transport difficult to envisage.

The principle of exergy-saving for reducing the environmental impacts of resource consumption, which was briefly touched in Chapter 2.8.1, is particularly important for the resource analysis understanding of industrial ecology. This principle can be used to further support the argument of using renewable energy in place of energy based on combustion of deposits, such as fossil fuels. With the use of renewable raw materials as a source of energy, the exergy loss is smaller than the comparable exergy loss from combustion of fossil fuels. Fossil deposits have been formed through natural processes with duration of millions of years, removed from the recycling processes in the biosphere. This has given them higher exergy content than biological raw materials, which are part of the renewable flows. By using fuels based on renewable biological raw material, instead of fossil fuels, exergy can thus be saved. A transition from today's extensive usage of fossil fuels in transport to a future with more of the fuel produced from renewable material is therefore compatible with the principle of exergy-saving. The study of exergy flows in industrial ecology can thus contribute to a transition away from exploiting deposits and in the direction of using renewable resources instead. An exergy tax has been suggested in this respect, to support the necessary changes in a sustainable direction. The future of today's resource use, of which a major share is for transport activities, is aptly characterised by Wall (1997):

> "The present resource use in the society is a dead-end technology".

2.10.5. Conclusions on transport in the types

The conditions for including transport in the product-design understanding of industrial ecology are limited in several ways. The most striking limitations are connected to the main focus on efficiency aspects of transport problems. The limited view on nature's complexity tends to reduce the transport problems to mainly technical challenges. The conditions are not favourable for including problems of a more systemic character, such as the volume problems connected to transport. The narrow interpretation of dematerialisation, without taking into consideration that there has been a large increase in transport volumes, also emphasises this. The conditions for further dematerialisation are not sufficiently present, as these are dependant of major changes to the production and consumption systems. The product-design understanding is thus well suited for dealing with problems related the design and manufacture of single products, such as automobiles, but not for the problems connected to society's increased mobility.

There are several forms of limitations for the inclusion of transport in the eco-park understanding of industrial ecology. The main focus on material use relative to the minor focus on energy represents a limit in this understanding's inclusion of transport issues. Important transport issues such as the transition to alternative renewable energy forms and increased energy efficiency are seldom addressed. Also the central focus on waste trading and utilisation of waste takes the attention away from reducing waste products being produced in the first place. This has implications for the volume problems of transport, which in this understanding is addressed only at a limited extent. It is limited to the systems of recycling being considered in this understanding, such as the clusters of industries making up a single eco-park. This understanding implies a major focus on establishing recycling systems, which might actually generate more transport in some cases.

In the CEM understanding of industrial ecology there are clear limits for the inclusion of problems in the form of volume problems of transport. These problems are connected to distribution of raw materials and finished products. The practice of outsourcing transport to contractors reduces the companies' possibilities for influencing the distributors of the products, regarding the environmental impacts along the whole product chain. The emerging concept of corporate social responsibility could however imply a change towards increased attention to the volume problems of transport.

The factor X understanding of industrial ecology, to a certain extent, addresses volume themes of transport. Input management of production systems could be important in obtaining the required increase in resource productivity prescribed in this understanding. The high dematerialisation rates prescribed are however difficult to envisage in combination with increases in global transport volumes. This is one of the few understandings where energy issues are reasonably well included, thereby increasing its applicability for dealing with problems connected to energy use in transport activities.

The understanding of industrial ecology as a framework for resource analysis is important in identifying resource limits connected to the production of transport means. Particularly regarding future energy-conversion and -storage systems can this understanding provide knowledge of metal scarcity and other constraints for a sustainable industrial metabolism. It is also evident that exergy analysis could aid in the transition away from exploiting fossil deposits into a future based on renewable sources of energy.

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3. Industrial Ecology and some Implications for Rural SMEs

3.1. Abstract

In a project at Western Norway Research Institute, the concept of industrial ecology is used as a framework for environmental performance of small- and medium sized enterprises (SMEs) in Norway. The main goal of the project ‘Green SMEs’ is to identify existing and future environmental challenges for rural SMEs. The focus is on external demands coming from the surroundings of the individual businesses. Examples of issues being dealt with are industrial wastes becoming sources of raw materials for other industries, design and material choice for disassembly and reuse, development of industrial ecosystems, and industrial metabolism.

This paper presents actual examples of industrial ecosystems and also some cases illustrating the problems small remotely located firms meet when the principles of industrial ecology are to be applied. These problems include the inability to participate in efficient industrial ecosystems (webs) with exchange of wastes to raw materials. Larger companies, often being more centrally located, have greater chances at identifying and attracting other businesses, which they can co-operate with in finding usage for their wastes. The ‘cluster’ properties of efficient industrial ecosystems can therefore be a limiting factor in the development of such systems in rural areas. Small companies also have less opportunities to be proactive in establishing industrial ecosystems also merely due to the smaller scale of their operations.

3.2. Introduction

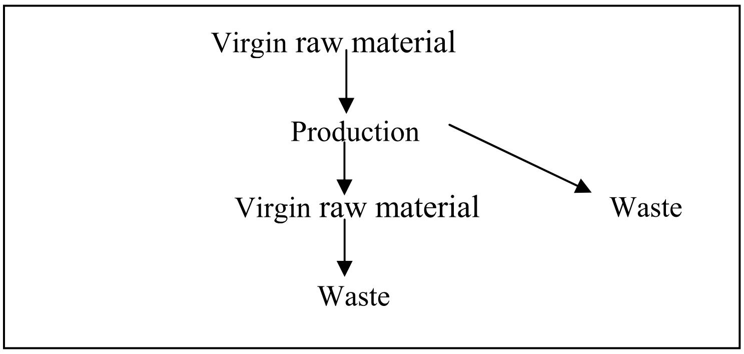
Deep ecology, as originally formulated by the Norwegian philosopher Arne Næss (1973, 1984a, 1984b), and later developed further by (among others) Næss (1989), McLaughlin (1993), Fox (1990) and Welford (1995) can be considered as having had an influential role on the work of the World Commission on Environment and Development and its report ‘Our Common Future’ (WCED, 1987). In the wake of the introduction of the concept ‘sustainable development’ in that report, the metaphor industrial ecology has evolved, using the ecosystems of nature as models for industrial systems.

Industrial ecology can be considered a third paradigm of corporate environmental management (Frosch, 1995). The two previous approaches have been end-of-pipe pollution control and pollution prevention. The more comprehensive approach, in which the industrial enterprise is viewed as an integrated part of its surroundings, has been launched as the new environmental agenda for industry (Tibbs, 1992). Industrial ecology implies that a holistic approach is taken where not only the product chain, but also whole industrial systems and networks become the issue. A result of this is that increased demands are on the responsibilities of the manufacturer for the safe use and disposal of the products. Ease of dismantling, recycling or reuses are beginning to be taken into account when designing new products (design for disassembly). Industrial ecology focuses on technology development as the key to a desirable global state (Allenby, 1994). A logical consequence of this technology-reliance is that the design segment of the industrial ecology concept is being incorporated into the engineering training by introduction of new curricula for the engineering students. One example of this is at the Centre for Environment and Development at the Norwegian University of Science and Technology in Trondheim. Here industrial ecology is viewed as the 'driving force' for *environmental life-cycle technology management and sustainable product design.* This in turn implies that the engineering field will have to focus on *cleaner production process design* and development of *technologies for recycling* (Brattebø, 1996). The role of the universities is further emphasised by Ehrenfeld (1994) and the fact that industrial ecology programmes are offered at several educational institutions in the USA, among others Princeton University, University of Michigan, Harvard University, New York University, Massachusetts Institute of Technology, Spelinan College in Atlanta, University of California in Los Angeles, and Dalhousie University in Halifax, Nova Scotia. The concept is also included in the 'Cleaner production, cleaner products, industrial ecology & sustainability' programme at the Erasmus University in Rotterdam, Netherlands.

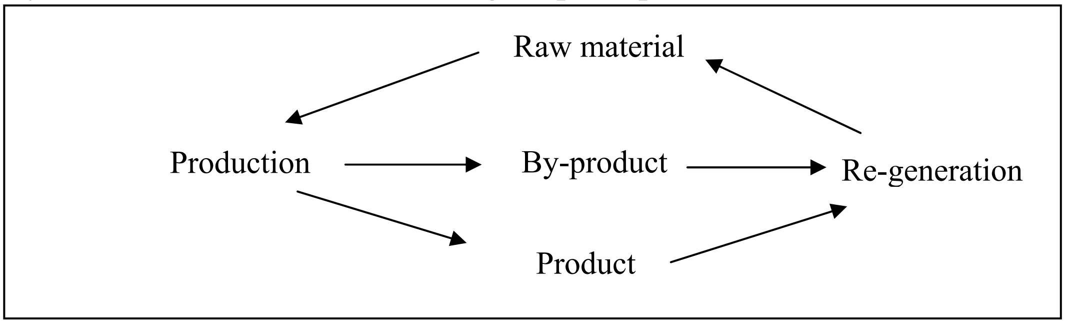
A major inspiration of the industrial ecology conceptual development was the work on industrial metabolism by Ayres (1989). By optimising the flow of materials in the industrial systems using as a model the metabolism found in nature, with its efficient process steps with high yields (often 100%), the rationale is that the industry will have a *built-in insurance against further environmental surprises,* because their essential causes will have been designed out (Tibbs, 1992). This is obviously an optimistic claim, and is based on the strong faith in technology and its ability to solve future environmental problems. An observed reduction of the volume of raw materials used per unit of gross national product (GNP) is also claimed to constitute a process of 'dematerialisation'. As Bunker (1996) points at, this however gives a wrong picture of material usage, because it fails to recognise that the absolute volumes and distances transported of major raw materials have increased over the same periods for which dematerialisation has been claimed.

Figure 21 *Schematic presentation of the transition from traditional linear material flow to a cyclic flow based on ecological principles*

Linear material flow:



Cyclic material flow based on ecological principles:



A transformation from traditional linear to cyclic material flows (*Figure 21*) is of fundamental importance in the industrial ecology concept. This implies a focus on finding usage of wastes, and this can both become a challenge and an opportunity for businesses. The development of industrial parks, also termed 'industrial ecosystems' (or 'industrial ecological clusters'), is necessary to facilitate efficient exchange of wastes for raw materials. Successful application of the principles of industrial ecology requires that the implications for rural SMEs are well known. Local and regional socio-economic and environmental conditions must be accounted for when implementing increased reliance on recycling principles.

The close proximity of businesses taking part in an industrial ecosystem is of ultimate importance to reduce the amount of transport of waste material. A result of this is that industrial ecosystems to a great extent occur as clusters often surrounding one or a few 'core'- industrial facilities. Many such industrial ecosystems are beginning to emerge, mainly in the USA, but also to a lesser extent in Europe. One example is in King County in Seattle where the Duwamish coalition and the local economic development office are conducting an industrial ecology study of the Duwamish industrial corridor. This is an area where decades of intense industrial use have resulted in the contamination of sediment, soil and water, as well as the loss of natural habitat along the Duwamish waterway and on upland properties. Contamination is especially hazardous in the corridor because pollutants move via groundwater and surface water runoff, reaching the river and Elliott Bay and entering the food chain through fish and other wildlife.

Contamination is also of great concern to people living in nearby residential communities. There is great need for cleaning up existing contamination and preventing further pollution in the area. The U.S. Environmental Protection Agency (EPA) has given a grant to the county's Economic Development Office in the Department of Development and Environmental Services. It is used to identify waste products generated by manufacturers in the Duwamish industrial corridor. Everything from toxic chemicals and sandblasting grit to scraps of fabric and leather from garment manufacturing that can then be recycled into other products as soft as pillows or as abrasive as the stones used in grinding wheels are included. Another example of industrial ecology projects in the USA is the President's Environmental Technology Initiative, funded through EPA and sponsoring a prototype industrial ecology project in the Brownsville, Texas/Matamorous, Mexico border area. The EPA hired the North Carolina-based Research Triangle Institute to provide the necessary background and research support for developing and operating an eco-industrial park in the area. A guidebook to assist other communities in setting up eco-industrial parks was prepared by Indigo Development, a California-based international design company, which specialises in the redeveloping of industrial parks and facilities to optimise both environmental and economic performance.

In Europe, a good example of an industrial ecosystem is around the city Graz in Austria, where a business recycling network exists using more than 1.2 million tonnes of residuals annually (Linnanen and Halme, 1996). In several types of industries, particularly materials focused, integrated chain networks or industrial ecosystems can be seen emerging in Germany. Current examples are found within the chemicals industry and the automotive industry where material circulation networks are being established (Wagner and Matten, 1995). The integrated chain management experiments in the Dutch industry can also be viewed as a form of holistic approach resembling industrial ecology, although it is somewhat more limited compared to a whole industrial ecosystem (Cramer, 1996).

Kalundborg in Denmark is however the most often used example of a successful industrial ecosystem. In this small industrial city of 20 000 several businesses in close proximity to each other exchange and make use of their industrial by-products. The local electric plant supplies surplus steam (which would otherwise be condensed into a local fjord) to a refinery and a pharmaceutical plant. A wallboard producer buys surplus gas from the refinery as a replacement for coal, and removes the sulphur from the gas and sells it to a sulphuric acid plant. The electric plant uses its surplus heat to grow trout and turbot, and sells sludge from the fish farm as fertiliser to local farms. This industrial ecosystem makes productive use of otherwise unwanted industry outputs, increasing productivity and efficiency while at the same time decreasing impacts to the environment. The economics of this scheme is large, of a total investment of USD 60 million, the groups participating annually receive USD 10-12 million payback. Total earnings are estimated to USD 120 million as of 1995 (Edgington, 1995). In Kalundborg however, a cluster of industrial firms already existed, the new fact was that they began to co-operate in solving environmental problems by exchanging wastes for resources. Due to the close proximity of the industries involved, the transport of the materials are minimized, and negative environmental impacts of material transport can be kept low.

The concept of industrial ecology does however imply some problematic issues of particular significance for SMEs. The establishment of efficient industrial ecosystems, where wastes from one process can be used as raw materials for another industry is essential for obtaining efficient material exchange. In order for a rural SME to participate in an efficient ecosystem, the wastes from the enterprise often must be transported over long distances, with the resulting negative impact on the environment, to find suitable usage. This again emphasises that the implementation of the practices of industrial ecology must take into account the implications for rural SMEs to be successful.

3.3. The problematic recycling society

The strong emphasis on material recycling that the industrial ecology approach implies is often not viewed critically. One example where design for recycling is being applied is in automobile manufacturing. Economic incentives, such as deposits or refunds to further encourage recycling, are also being applied. The efficient recycling of car parts can only be obtained if the cars are exchanged before they become so old that the parts are worn out. Associated with this issue there has been a discussion of whether forced exchange of new cars for older ones will give environmental gains. Reduced fuel consumption and reduced emissions would be possible additional benefits with frequent exchange. Results from several life-cycle assessments focusing on this issue do however support the opposite conclusion. With regard to energy consumption and emission of greenhouse gases there are no immediate gains. Total emissions of primary local importance are however reduced (Høyer, 1997).

Extensive recycling can actually imply more transportation and larger environmental problems following the demands for energy and the infrastructure to support the transportation. This is particularly relevant connected to the activities of rural SMEs. A question can also be asked whether the extensive recycling is the most efficient solution. The 'inverted logistics' of returning and re-manufacturing goods back into useful raw materials are not well developed (Jahre, 1995). For some products it can cost up to nine times as much to recycle the product (reverse logistics), compared to producing it and transporting it to the customer. This is in part due to the inability of the goods to be transported and stored as in the traditional linear forward material flow. Also uncertain supply, determined by when products are used up, contributes to this problem. One example of this problem is the taxation system introduced through the German packaging take-back policy. These taxes are now 4-5 times higher than when they were introduced two years ago. This demonstrates the large discrepancy between the presumed and the actual cost of recycling. A major problem has been in household recycling. For some homes up to 32 cars are now picking up sorted garbage, compared to only four cars before the recycling system for waste started. This example illustrates some of the problems associated with the transition into a society where the emphasis on recycling is rapidly increasing.

3.4. The Green SMEs project

In the project at Western Norway Research Institute some of the principles of industrial ecology are used in establishing environmentally sound practices in SMEs. This is not without problems, as industrial ecology is a concept that originated from leaders of large industrial corporations, and is not always well suited for small operations. SMEs in Norway almost always have limited resources, and the government support through research projects is of significant importance. The 'Green SMEs' project is financed by the Norwegian State Department of Local Government, who supports the policy of keeping the rural SMEs alive as one of the prerequisites for continued desirable regional development.

3.4.1. Goals of the project

The project aims at developing knowledge of the transitions SMEs has to go through to be prepared for environmental demands in the future. The knowledge obtained is transferred to the enterprises, to make them more compatible with the principles of sustainable development. At least 90% of all businesses in Norway are SMEs, and as the national environmental authorities mainly focus on the large industrial companies, there is much need for this knowledge.

There has never been a goal in this research project to compare the individual cases of SMEs. Rather, there has been emphasis on identifying general problems the regional SMEs has to cope with in the future. The transition to a society where the principles of industrial ecology are increasingly applied represents one framework for such problem identification.

3.4.2. Methodology

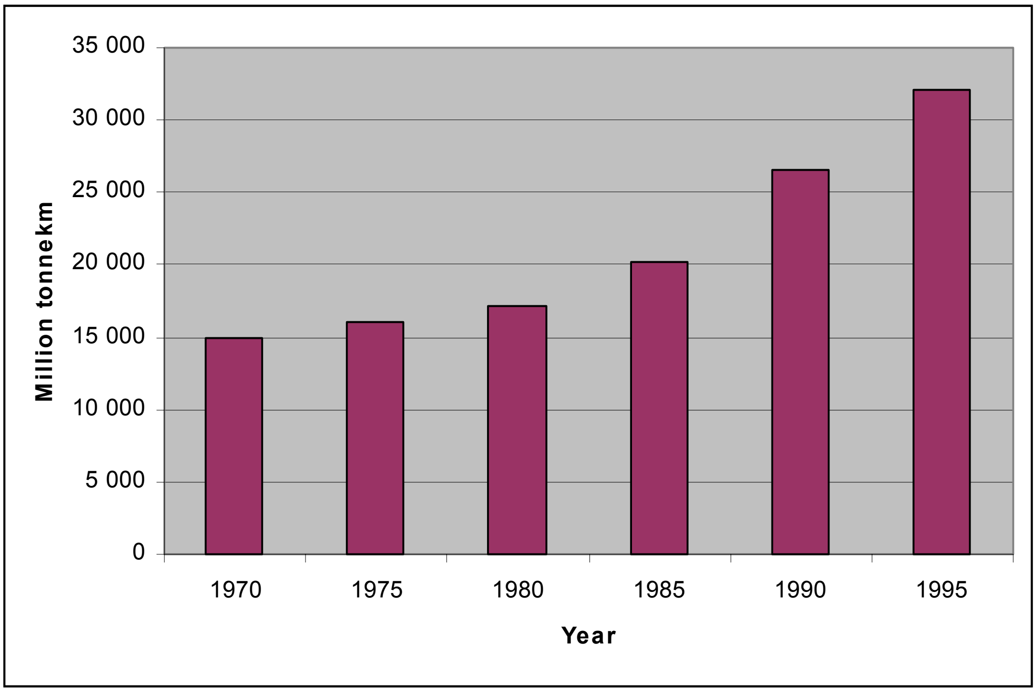
During the 'Green SMEs' project several different approaches in the work with the enterprises have been applied. In two companies a detailed mapping of energy- and material usage was performed. The enterprises were then given suggestions of how to become more efficient in their use of energy and raw materials. There was a focus on technical improvements that in addition to have environmental benefits, would imply cost savings, and in that sense it was inspired by a pollution prevention pays (3P) approach as developed by Minnesota Mining and Manufacturing (3M) in improving industrial metabolism. In a third enterprise a different method was used. This consisted of building up elements of an environmental management system. The approach implied that the main focus was on the internal routines necessary to ensure quality assurance as a prerequisite for successful environmental management. The work with these three companies constituted what is called Phase I of the project.

In phase II of the project a more focused approach was used. From applying a wide set of different approaches ranging from technical environmental audit to building up quality assurance and environmental management systems in phase I, a move towards viewing the enterprise as a function of its surrounding environment was taken for phase II. The focus shifted towards the demands coming from outside the factory walls. The internal working environment was still regarded important, but the main emphasis was on the relationship between the enterprise and its surroundings. Industrial ecology is one example of such a demand from the outside. The other challenges from the surroundings in this context are (among others) customer demands, supplier demands, pressure from environmentalist groups, government regulations, banks and insurance companies. To be able to identify the most important environmental demands that the individual SME has to meet, a quick first audit is performed followed by a report where themes for further work are suggested. Depending on the response from the company management on the suggestions, further work with the enterprise was performed. The first audit served as a tool to give a 'snapshot in time' of the SME and its relationship with its surroundings.

3.4.3. Results and discussion

The different approach used for phase II of the project was chosen on the basis of the experiences with the different methods used in phase I. The extensive mapping of internal company issues, such as energy- and raw material usage, gave many small improvements for the environment. The experience with the enterprises in this project was, however, that there are other issues than those that can be identified during a detailed technical audit, which are the most important for the environmental performance of the SME. The environmental impact of the individual firm is strongly determined by what type of product-chain the enterprise is a part of. Most of the SMEs are tightly connected with other companies that make up a production network. This must be viewed as a whole to assess the environmental effects and demands on the individual enterprises. The more holistic approach, which industrial ecology represents, is useful in this respect, because it is not limited to improving the environmental performance of the individual SME. The industrial ecology concept however, does not cover all features of manufacturing goods as demonstrated in the following example: two of the SMEs in the project are part of the same industrial production chain, one a producer of food for fish farming, and the other a producer of polystyrene boxes for packaging, mainly for transport of the frozen fish. The greatest environmental impact of these two enterprises are found within the production chain they are part of, and is likely to be the transport of the fish to the customer. A rapidly growing and large market for fish from Norwegian salmon farms is the Japanese market. The fish is transported over long distances by aeroplane to the customer, and thereby gives large environmental impacts. Reduction of transportation (by providing goods and services as close as possible to the consumers, according to the proximity principle) was one of the four changes needed to attain a society based on sustainable consumption agreed upon by the Commission on Sustainable Development meeting in Oslo in January 1994 (Høyer, 1997). The goal of *reducing transportation is* outside the usual scope of the industrial ecology concept. The transport issue is particularly important for Norway, because transportation over long distances is often necessary due to the scattered geographical distribution of the population. The growth in domestic transport of goods has been exponential during the last 25 years in Norway (*Figure 22*) with the corresponding negative implications for the environment.

Figure 22 *Domestic transport work of goods in Norway from 1970 to 1995*



Source: Rideng (1996)

Another company participating in the 'Green SMEs' project is a producer of advanced filtration systems for water purification. Design for disassembly is an industrial ecology principle that could be used to make the products more compatible with the trends in one of the main product markets, oil-drilling platforms in the North Sea. After the Brent Spar event, where the plans by Shell to dump the platform were withdrawn, future dumping of oil-platforms will not likely occur. Since the enterprise supplies the platforms with advanced filtration systems, these also will have to be disassembled after final usage. Without taking this trend into account in its product design, the company will not contribute to facilitate recycling of the end product. This company is also in the process of implementing technological solutions for remote training and servicing based on the virtual reality (VR) concept. This is partially motivated by environmental factors based on the assumption that this technology will reduce the necessary travel for service personnel and staff training during implementation of new production units. Many reports however have shown contradictory effects of telecommunication solutions on travel (Niles, 1994). Travel stimulation and urban sprawl (geographical dispersal) of people and goods are some observed effects of telecommuting. The magnitude of the urban sprawl occurring is however dependent of the spatial distribution of the population. There are substantial empirical data indicating that the urban sprawl indeed causes increased transportation with its corresponding negative effects on the environment. The same reasoning as for telecommuting applies for regional small businesses implementing advanced information technologies such as VR to communicate with people remotely located.

The extensive use of waste as raw material is the foundation for the existence of a different firm in the project. This enterprise utilises cut-offs from the fish processing industry and animal waste from slaughterhouses as the major raw materials for the production of animal food to fur farms (fox and mink). Within the concept of industrial ecology this enterprise and its suppliers can be viewed as being parts of an industrial ecosystem exchanging wastes for raw materials, but from ethical and animal rights point of view this production chain is not desirable. A relevant question would be if it is ethically acceptable that thousands of animals must be deprived of their freedom and instead be kept in cages to produce a product that to a large extent can be substituted by materials produced by more benign methods.

A bakery participating in the project finds usage for their wastes (from bread kept too long time in the ovens etc.) by giving it to local pig farmers. This is another illustrative example of an SME being part of an industrial ecosystem where waste is used as raw material for another process (pig farming). The effect of supporting pig farming in the transition into a sustainable future is however questionable, as there is increasing acceptance for the need to move towards a consumption pattern consisting of less meat and accordingly more vegetables, to be able to cope with the food demand for the rapidly growing global population. This idea might seem remote from the individual SME, but it does illustrate the difference between day-to-day activities and long-term strategy building based on ecological principles.

A ship building company is also participating in the Green SMEs project. This firm utilises large quantities of steel as raw material in the production of the vessels. The environmental demands for this SME will probably not be associated with its production activities, but rather concerning the raw material consumption and the usage of the finished product. One way, in which this company can prepare for the environmental demands of the future, and in accordance with industrial ecology principles, is by increasingly applying recycling principles when choosing raw material. By demanding that a high portion of the steel used as raw material is recycled steel, this enterprise can be environmental proactive when selecting suppliers. One other issue that might become relevant for this SME is the usage of the final products (ships). Is it possible for this company to secure that the finished ships are not involved in illegal over-harvesting of limited food resources in the oceans? How will the principles of extended product liability, which are becoming more common, affect this SME in the future?

3.5. Conclusions

The principles of industrial ecology can serve as a useful framework for corporate environmental strategy forming, and for identifying environmental challenges that SMEs can meet in the future. It can also function as a guiding tool to identify environmental problems of particular relevance for rural enterprises, such as the inability to participate in efficient industrial materials recycling systems. Several environmental aspects of manufacturing relevant for SMEs are, however, not usually dealt with within the framework of industrial ecology. This is especially true for the transportation reduction necessary to attain a society based on sustainable consumption. The transition towards the high level of recycling that the industrial ecology approach represents is rather problematic when the environmental performance connected to the transport activities of the rural SMEs is considered. The most critical environmental issues for rural SMEs are not emissions from the individual industrial facility, but rather the external challenges facing the businesses. The products being produced, the distribution of raw materials and products, and the production chains the firms are parts of, are becoming increasingly important for the rural SMEs.

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4. Transport of Fish from Norway: Energy Analysis using Industrial Ecology as Framework

4.1. Abstract

In this article, industrial ecology is used as a framework for analysing transport energy and its implication for products. The importance of the energy use for transport in a natural resource production system is analysed. By using fish as case, it is shown that the amount of energy for transport is highly dependent on the transport mode used. When applying industrial ecology principles for making assessments of the environmental impacts of products, the whole product chain is examined. This is an extended life-cycle approach, which also includes the transport of the finished products from the exporter to the importing country. This last part of the transport chain can be extremely energy demanding, as is shown for the case of fish transport. This finding has implications for the products, and what form the products should be transported in. Increasing the energy efficiency of production systems is an important industrial ecology principle, and must be taken into consideration when analysing product chains. A revision of today's practice of transporting large quantities of fresh whole fish by transcontinental airliners is bound to be necessary. This is a consequence of the demands for increased energy efficiency of tomorrow's industrial production systems.

4.2. Introduction

Industrial ecology encompasses a wide range of issues connected to the relations between industrial production systems and the environment. Included are energy and material resource use, emissions to air, water and land, during the whole production chain. The whole chain in this respect consists of extracting and processing of raw materials; manufacturing, transportation and distribution; use/re-use/maintenance; recycling and final disposal (Graedel and Allenby, 1995). It is however not equally emphasis on the various aspects of the chain in the industrial ecology field. First of all, the energy use considerations are not well focused on compared to what is the case for material resource use. This has been pointed to earlier by O'Rourke et al. who states that:

> …It is rather odd that energy flows in natural ecosystems are largely neglected. In an introductory text on ecology, Kormondy writes, "…a one-way flow of energy constitutes one of the most important if not the cardinal principle of the ecosystem" (Kormondy, 1969). If energy flows – not material flows – are "one of the most important" principles of a natural ecosystem, then industrial ecology should place at least equal emphasis on energy flows and how they change as ecosystems evolve.
> (O'Rourke et al., 1996)

Secondly, there is strong focus on issues connected to extraction, processing, manufacturing, waste utilisation and recycling. Transport in connection with the various segments of the production chain is only scarcely considered. Analyses of the energy use and environmental effects of distributing the products are missing in particular. The perspective on products in industrial ecology is however quite strong, and integrated with the energy and material flows. The design and manufacturing of environmentally friendlier products are highly relevant, as the statement by Robert Frosch points to:

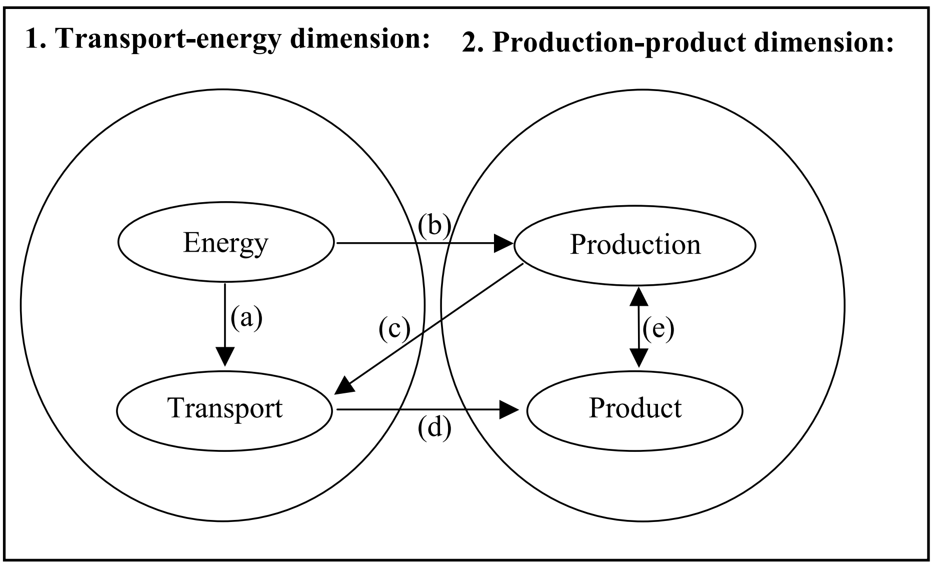
> "A product is a transient embodiment of material and energy occurring in the course of material and energy process flows of the industrial system."
> (Quoted in Ehrenfeld, 1994)

Product Life Cycle Assessment (LCA) is an important tool in industrial ecology. However, the LCA approach often fails to include the trans-national transports from producer to the customer. The wide approach that is represented by industrial ecology should have focus on all the life-cycle stages of the products and the environmental demands along the whole product chain. If transport in the product chain is not included, important environmental effects of the products are omitted. This is problematic when facing transport's contribution to major environmental problems (Høyer, 2000). Including the transport considerations in the product chain might result in other demands to the products. Hardly any of the various understandings of the concept industrial ecology include the transport considerations along the complete product chain. If these considerations were included, other answers to the question of environmental impacts might be obtained. Fish is the product case used in this article to illustrate this issue.

There is particular reason for concern regarding the energy use for transport of raw materials and finished products. The increased globalisation of the economy causes raw materials and particularly finished products to be transported over longer distances, resulting in steadily higher energy use for these parts of the industrial production chains. This serves as a background for this article's focus on the *products* being produced. The connections between the main issues dealt with in this article are summarised in *Figure 23*. The figure illustrates that the article discusses issues along two dimensions:

1. The transport - energy use dimension
2. The production - product dimension

Figure 23 *The main issues being dealt with in this article, and their connections*



In the transport-energy dimension (1) a discussion of the energy use in transport is carried out (a). This is based on an analysis of the energy use in the various transport activities in the production chain. The energy use in the production chain also includes stationary energy uses (b). This is also dealt with in the article, but seen in light of the relative higher importance of the energy use for transport. The type of production considered has implications for transport choices (c), while the transport itself has implications for the product type (d). This brings us over to the production-product dimension (2). The energy use for transport in the production chain has implications for the products being produced (e). Particularly the transport of finished products to the customers can require excessive energy inputs if the product is in a form not suited for transport by energy-efficient transport modes.

The research presented here is based on the hypothesis that the environmental impact, in the form of increased energy use and emissions from the transport of raw material and finished products in most cases are underestimated. The empirical material is from research in energy use of natural resource-based industries. Transport of goods is large in the natural resource-based industries, and particularly the strong increase in air- and lorry-based transport is problematic for many reasons. Both in terms of energy use, emission of CO_2, and congestion of the air space and the European road network, this increase is undesirable. Changes in transport modes are necessary to combat these problems. Transfer of today's road based goods transport to more energy efficient rail and sea-based transport will be required in the future. Likewise will limitations on goods transport by air be required. The application of a wide range of measures and actions are necessary to obtain these changes in the systems for transport of goods. Substantial environmental gains will however only be obtained after major changes in the production systems, particularly regarding in what form and where the products are transported.

The theoretical framework applied in the research presented here is industrial ecology, while fish is the case product. Some aspects of this choice of case product are described in the following. The historical development in Norway points to the problem that while the total volume of fish catch is approximately at the same level in 1990 as in 1960, the energy use in the fisheries has three-doubled over the same time period (Høyer and Groven, 1995). This is partially explained by longer transport distances for each boat to the fish-rich waters. This emphasises the development towards a steadily more energy-demanding fishery where increased transport is an important component responsible for this change.

The change in the energy use in the production segment of the product chain is important to be aware of. For the fish sector, a wide focus on the production segment implies that not only the activities of the fishing boats and the fish farms are included, but also the transport of the raw materials (fish feed) and finished products (fish for sale). This wider approach also has relevance in the discussion of sustainable development. There have been tendencies, both in politics and research, of a narrow understanding of the term ecological sustainability. In fisheries this is made into a question of staying within the maximum sustainable yield for the species. In principle, then, it may be ecologically sustainable to establish a fishery consisting of a small fleet of energy-demanding trawlers, which makes sure that the catch is kept within the sustainable yield. Similarly, a sustainable aquaculture can be defined, as long as certain criteria, such as minimal pollution from the facilities, are fulfilled. Consequently, there is in principle nothing to prevent the export of fish by jet plane from Norway to Japan. It is evident that this is not consistent with the understanding of ecological sustainability that ensues from the term sustainable development, for example in the way it is described in the Brundtland Commission report (WCED, 1987).

A wider ecological sustainability perspective of the whole product chain must also be applied in industrial ecology considerations. This is necessary when making efforts to determine the magnitude of energy input into products. The energy use of both upstream and downstream industrial activities must be considered. It is necessary to include the energy use for production and transport of fish feed for aquaculture. Also the transport system for the finished products is included. This is of particular importance since the energy use for transport contributes large in general to the total life cycle energy input in products (Høyer, 2000).

4.3. Method and data material

The data material forming the empirical base for this article is mainly drawn from two research projects carried out at Western Norway Research Institute. The first research project is "Local and global environmental challenges as conditions for rural development". The project was part of the programme for research on rural development in the "Department for bio-production and breeding" at Norwegian Research Council in the period 1992-95. One of the core questions asked was: How large is the energy use for transport in fisheries and aquaculture (fish farming)? Data on energy use were obtained for the segments of the fish product chain that was assumed to be the most important. For the calculation of energy use in the aquaculture fish feed production chain in Norway in 1980 and 1994, data were obtained from Norwegian fish feed producers and the Norwegian Herring Oil and Meal Industry Research Institute. The segments of the aquaculture fish feed production chain and their 1994-specific energy use (in parenthesis) are: 1) Catch of fish feed raw materials (1 552 kWh/tonnes), 2) production of fish flour (3 210 kWh/tonnes), 3) import of fish flour (148 kWh/tonnes) and 4) production of feed-pellets (249 kWh/tonnes). The origin of the imported fish flour material is assumed to be as follows: 50% from Iceland, 25% from Denmark and 25% from Chile. The energy use for production of fish flour is assumed to be the same in these countries as in Norway.

In the calculations of the energy use in the distribution of the exported fish, three main categories of fish are analysed: 1) Fresh and frozen fish to Europe, 2) frozen fish to East Asia[21] and USA and 3) fresh fish to East Asia and USA[22]. Norwegian Seafood Export Council supplied the data on the amounts in 1994 for each of the three categories.

[21] Japan, Taiwan, Hong Kong, Singapore and Korea.
[22] This constitutes 98% of fresh fish exported from Norway to USA and other overseas countries in 1994.

The data on energy use, load capacity, load factor (utilisation of load capacity) are based on data for the boats to East Asia operated by Maersk Line[23].

The calculations of the energy use in feed-production and transport of overseas export of frozen and fresh aquaculture fish are based on a total of 222 000 tonnes harvested aquaculture fish in 1994. This number was provided by Kontali Analyse AS (www.kontali.no).

The other research project from which the empirical base for this article is drawn is “Energy saving in transport of goods – a pilot project in rural natural resource-based industries”. The project was part of the programme for research on “Specific Actions for Vigorous Energy Efficiency” (SAVE) in the European Commission Directorate-General for Energy, DG XVII and was carried out in the period 1998-2000 (Andersen et al., 2001). The main objective of this project was to develop and implement actions, strategies and measures for improved energy efficiency in transport of goods. The project covered rural natural resource-based industries from 3 different branches. All “cases” were transport in connection to rural natural resource-based industries in the 3 Nordic countries Finland, Norway and Sweden. The three branches were transport in forest industry (Finland), fishing industry (Norway) and agriculture industry (Sweden).

The data material included in this article is on the transport of fish from Western Norway to the European continent. A total of four different cases for transport of fish, which was used in 1998/99, were analysed in detail in this project. All four cases were operated by one transport company and the cases were mainly based on lorry transport[24]. One of the four cases is analysed in detail in this article. The main results of the other three cases are however discussed for generalisation purposes. The analysed cases all included a segment where the lorries were transported by ferries. The case which is presented in detail in this article is the transport of dried cod to Italy (Torino/Foligno) with lorry from Ålesund to Oslo, ferry to Copenhagen, lorry to Gedser, ferry to Rostock, lorry to Manching, rail (lorry on rail) from Manching to Brenner, and lorry on the last distance to Foligno.

For the calculation of energy use for the case route in 1998 it is assumed an energy content of 9.76 kWh per litre diesel fuel used by the lorries. The ferries are assumed to travel with an average speed of 37 km per hour. The specific energy use for each of the two transport modes ferry and lorry-on-rail is 0.50 and 0.11 kWh per tonne-km respectively.

[23] For the calculation of energy use in the export of frozen fish to East-Asia and USA it is assumed that the transport is carried out by 60 000 dwt. container boats, with a capacity of 7 500 tonnes frozen fish total, in 300 containers with 25 tonnes fish each. It is further assumed a fuel consumption of the ships of 150 tonnes heavy oil per 24 hours. The energy content of the heavy oil is 11.65 kWh/kg, and the boats travel with an average speed of 24 knots. The energy use per 24 hours with full load capacity is 32.5 kWh/tonnes fish transported. This includes 3.8 kWh for the operating the freezing aggregates during the transport. Average load factor is 52.5% (80% to East-Asia, 25% on the return trip).

[24] The fuel consumption by the lorries was measured using the on-board Volvo Road Relay system. This was supplemented with manual logs completed by the drivers using dedicated logbooks on the routes.

The case routes are compared with a scenario for 2015. This scenario presupposes major changes in the transport systems in Europe, such as increased capacity of the rail systems, and increased efficiency of harbour operations (Hansen et al., 2000). The energy use factors applied in the calculations for 2015 and changes since 1998 are shown in *Table 5*.

Table 5 *Energy use factors applied in the calculations for the 2015 scenario*

Transport mean	**Energy use (kWh/tonne-km)**	*Change since 1998 (%)*
Boat (at 70% load factor)	0.08	0
Lorry[25] (at 60% load factor)	0.36	-10
Train[26], electric (at 70% load factor)	0.06	-25

4.4. Results

4.4.1. Aquaculture and energy use

The empirical data material presented here from the project "Local and global environment challenges as conditions for rural development" is previously published, in Norwegian language, in one of the reports from the project (Høyer and Groven, 1995). The report covers both what can be termed mobile fisheries (by boat) and stationary fisheries (aquaculture). The main focus in this article is aquaculture, which is the fastest growing of the two forms of fisheries. Both upstream and downstream energy uses are included in the analysis.

The energy use in the production chain of feed for aquaculture is analysed first. The Norwegian energy use for this segment of this form of fish production in the years 1980 and 1994 is shown in *Table 6*. From the table it is obvious that the energy use for catch of fish flour raw material dominates the picture. This can be explained in part by the large amount of raw material that is needed for fish flour production. Approx. 5 kg fish is needed for the production of 1 kg fish flour. *Table 6* also shows the tremendous increase in the energy use for the aquaculture industry in Norway during the last two decades. The increase in energy use in the feed production chain between 1980 and 1994 is actually more than 24-fold. This underlines the importance of considering the environmental aspects of this industry.

[25] Lorries are assumed to mainly be used for shorter distances in distribution- and supply transports. This explains the small improvement of only 10%.
[26] Trains are assumed to be powered by electricity only. The trains for goods transport are assumed to have maximum speed of 120 km/hr and with carriages for transport of containers/semi-trailers on 2 floors. Already at the end of the 1990's in Swedish and Finnish rail transport, an average 0.03-0.04 kWh/tonnekm (load factor 60-70) was obtained. A higher energy use factor than this is used to compensate for the weight of containers/semi-trailers.

***Table 6** Energy use in the aquaculture fish feed production chain in Norway in 1980 and 1994 (GWh)*

Segment of the chain	**1980**	**1994**
Catch of fish flour raw material	58.2	1 448.0
Production of fish flour	24.1	599.2
Import of fish flour[27]	-	6.1
Production of feed-pellets	5.4	85.3
Total	**87.7**	**2 138.6**

The energy use in the distribution of the exported aquaculture fish from Norway in the three main forms of fish export is shown in *Table 7*. It is evident from the table that the transport of fresh fish to East Asia and USA dominates the energy use in the export of aquaculture fish from Norway, comprising more than 70% of the total energy use.

***Table** 7 Energy use in the export of Norwegian aquaculture fish. 1994 (GWh)*

Category of the exported fish	**Energy use**
Fresh and frozen fish to Europe	105.7
Frozen fish to East Asia and USA	32.5
Fresh fish to East Asia and USA	379.2

To compare the different forms of fish transport in terms of energy efficiency it is necessary to also consider the amount of fish transported for each of the two product categories, frozen and fresh fish, which is exported to East Asia and USA. The amounts transported in 1994 were 15 751 tonnes frozen and 17 575 tonnes fresh fish respectively. It is then possible to compare the energy efficiency of the transport of the two product forms. An energy efficiency of 2.1 kWh per kg fish is obtained for the transport of frozen fish, while the transport of fresh fish requires 21.6 kWh per kg, thus a factor of more than 10 times difference in energy efficiency of the transport of two different forms of the same product. This large difference can be explained by analysing the energy use in the different segments of the two transport chains. This is done in *Table 8*, where the energy use in the different transport means and routes for the two forms of the fish product are shown in more detail. It is obvious from *Table 8* that it is the air transport that is the major reason for the high energy use of the transport of the fresh fish compared with frozen fish.

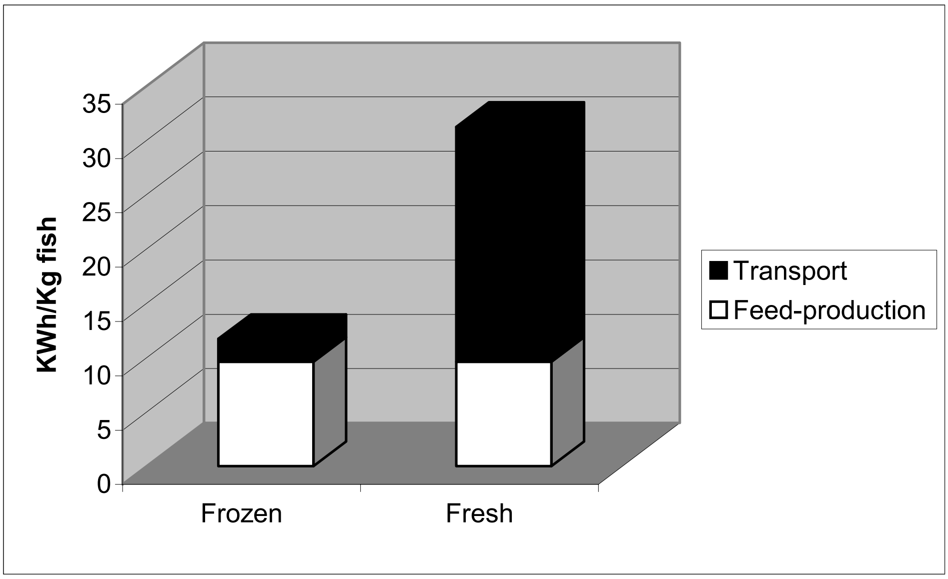
[27] Data for import of fish flour in 1980 is not available

***Table 8** A detailed look at the energy use in the transport of fresh and frozen aquaculture fish from Norway to East Asia and USA. 1994*

Product form, transport means and route	**Total energy use (GWh)**	**Energy use per product unit (kWh/kg)**
Frozen fish:		
• Lorry Bergen-Oslo	2.7	0.2
• Boat Oslo-country of destination	29.8	1.9
Fresh fish:		
• Lorry Bergen-Frankfurt	10.6	0.6
• Aeroplane Frankfurt-country of destination	368.6	21.0

Transport is the key factor in the calculations of the energy use in the two product chains. This is evident in *Figure 24*, which shows the transport's share of total energy use in the two product forms. The two bars show the energy use for feed production and export of frozen and fresh aquaculture fish. The energy use in the production of fish feed is the same (9.6 kWh per kg fish) for the two product forms. The large difference in energy efficiency between transport by boat and aeroplane results in a total of three times higher energy input in the fresh fish product compared with the frozen.

***Figure 24** Energy use in feed-production and overseas export of frozen and fresh aquaculture fish. 1994*



4.4.2. Fish transport in Europe

The following results are based on the analysis of the empirical material from the SAVE-project "Energy saving in transport of goods – a pilot project in rural natural resource-based industries". The fuel consumption, distances, durations and average loads for the case fish transport route are shown in *Table 9*. A total of four case routes were analysed in detail, but only the result from one of the routes is presented here.

Table 9 *Average fuel consumption, distances, time usage and load for the transport of dried cod to Italy. Round trips (from Norway to Torino and back to Norway). 1998.*

Lorry fuel consumption (Litre)	Road distance (km)	Ferry duration (Hrs)	Rail distance (km)	Total duration (Hrs)	Payload (Tonnes)
1 659	4 622	28	440	158	22

The energy use was calculated from the measured fuel consumption of the lorries and by using the factors for energy content of the fuel, speed of ferries, and energy use for ferries and lorry-on-rail presented in the methods section of this article. The results are shown in *Table 10*. It is clear from the table that the contribution to the total energy use from ferries is relatively large, even though the distance with transport of lorry on ferry is short compared with the total transport distance.

Table 10 *Average energy use for transport of dried cod from Western Norway to Italy and back to Norway. 1998.*

Transport mean	Energy use (kWh)
Lorry	16 192
Ferry	11 149
Lorry on train	520
Total	**27 861**

To achieve major improvements in energy efficiency, a change in mode from todays road-based transport into using more rail and boat transport is however necessary. The necessity for using the energy-demanding ferry transport to carry lorries would then also be less. The effects of such mode transfers, on the energy use, are analysed in the work for the Nordic Transport-political Network in the Interreg IIc-programme. In the report from the project "Optimal transport corridors based on a sustainability- requirement" the energy use and the product-time relationship for the four cases are studied (Hansen et al., 2000). The data material from that report has in this article been supplemented by updated data from the analyses in the SAVE-project (Brendehaug and Groven, 2001).

In 2015 the situation for the presented transport case is assumed to be either sea-based or rail-based. The sea-based transport is by boat from Ålesund harbour to Genova, and lorry the last distance to Foligno. The rail-based transport is lorry from Ålesund to Åndalsnes, with the rest of the distance by train to Torino. For the rail alternative significant reloading/recoupling will take place in Oslo, Gothenburg and Lübeck and at a total of four other rail-nodes in Germany, Switzerland (Zurich) and Italy (Milan). The same average payloads as for the actual transports in 1998 are used for the calculation of the energy and time usage for the case route in 2015. The results are shown in *Table 11*.

Table 11 *Energy and time use in the transport of dried cod to Italy. Round trips (from Norway to Italy and back to Norway). 2015*

Main mode	**Lorry distance (km)**	**Rail distance (km)**	**Boat distance (km)**	**Total duration[28] (Hrs)**	**Energy use (kWh)**
Rail	226	5 274	0	166	8 752
Sea	814	0	10 686	438	25 254

A comparison between the actual case in 1998 and the calculated scenario in 2015 is shown in *Table 12*.

Table 12 *The energy and time use for the transport of dried cod to Italy. Round trips. Actual data from 1998 and calculated data for rail and sea transport in 2015*

	Energy use (kWh)	**Time use (hours)**
1998 (Lorry-based)	27 861	158
2015 Rail	8 752	166
2015 Sea	25 254	438
% Change 1998-2015, Rail	*-69%*	*+5%*
% Change 1998-2015, Sea	*-9%*	*+177%*

From *Table 12* it is clear that the transport of dry cod by train to Italy in 2015 is significantly more energy-efficient with a 69% lower energy use compared to the lorry-based transport in 1998. The sea transport is also more energy efficient than the lorry-based transport. The rail-based transport in 2015 is similar in time efficiency (5% difference) to the lorry-based transport in 1998. The transport by

[28] An average speed of 80 km/hr is assumed for trains. In addition is 6 hours waiting time at each of the loading/re-coupling locations assumed. The average speed of boats is assumed to be 14 knots. In addition comes a loading and unloading time of 4 hours at each port. This might appear to be low, but it is due to the much-improved efficiency of the port operations. The average speed for lorries (including rest hours) is assumed to be 60 km/hour. This might appear to be low, but as pointed out earlier, the lorries are assumed to be used only for short distances in connection with the two main transport modes, at the beginning and the final segment of the case routes.

boat is however more time consuming. But since the product is dried fish, this is of less importance due to the long durability of this form of the product.

From the other three cases analysed similar results were obtained, with significant energy saving effects (ranging from 9% to 79% reduction) for changing from lorry to rail and sea transport. Increased time use is not an important barrier, and in some cases the time efficiency is actually better with rail than with lorry. In some of the cases with shorter total time use the fish is in its fresh state during the transport.

4.5. Final discussion

A central principle of industrial ecology is a transition to more energy efficient industrial production systems in the future (see e.g. Graedel and Allenby, 1995). In this article, the importance of the energy use for transport in natural resource production systems has been analysed. By using fisheries as a case, it is shown that the energy for transport dominates the picture. Particularly the transport of the finished products is extremely energy demanding.

When using industrial ecology principles for making assessments of the environmental impacts of products, the whole product chain must be considered. The energy input into products should also include the transport of the finished products to the customers. This has implications for the products, and for what form the products should be in when they are transported.

One production system that has increased rapidly the last decades, and is seen by many as promising for the future, is aquaculture. Regarding its energy usage, there are reasons for major concerns with this system. It has previously been shown that the energy use per produced unit of fish for traditional aquaculture (cage farming) is ten times higher than free ranching at sea (Folke, 1988). The transport component of the aquaculture production system contributes to this problem. An example of this is that a large part of the fish feed used in Norway is produced in South America. The problem of high energy use for aquaculture is further amplified when taking into consideration what happens with the fish after it is harvested. Most of the fish that is transported in its fresh state on transcontinental air flights are produced by aquaculture production techniques. As is shown in this article, the energy use per unit of product is 10 times higher for this transport compared to when the product is transported in its frozen state by boat.

The dominating trend the last few decades has been to transport whole fresh fish, consisting of more than 90% (w/w) water. However, further back in history, it was common to transport the fish with less water, processed and preserved in the form of dried or smoked. Intercontinental flights carrying whole fresh fish is an extremely energy demanding way of transporting a product that consists mainly of water. This is not an activity that is compatible with central industrial ecology principles.

If the energy efficiency of industrial production systems is to be improved, more of the goods will have to be transported with energy efficient transport modes.

This realisation has implications for what type of products can be transported over long distances in the future. The example taken from fish transport by air illustrates this by showing that in an already energy-demanding production system, the energy use must not be increased additionally by transporting the product over long distances in a form requiring the use of excessive energy. Instead, if the product is to be transported far, the transport must be carried out in a product form suitable for transport by an energy-efficient transport mode. For the case of the industrial product fish, such a product form is the frozen, dried or smoked, which can be transported by rail or boat. Without these considerations being applied in industrial ecology, the concept reduces its value as a useful framework for improving the industry – environment relations.

For transports shorter than transcontinental, such as within Europe, it is possible, at least in principle, to transport a product consisting of mainly water in an energy efficient way. This is however dependent on mode changes from today's road-based transport to the more energy efficient sea and rail transport modes. The cases analysed show that the same product types can be transported more energy-efficient by sea and rail, without increasing the time use correspondingly. In those cases of fish transport where the time use is increased, this is of little importance for the quality of the product, if it is in a form (frozen or preferably dried or smoked) that is suited for long periods in transport. This illustrates the importance of transport mode change for improving the energy-efficiency of the fish production system.

Transportation of whole fresh fish implies that also large amounts of potential waste material are transported. When the product is transported in the unprocessed form, the waste is dealt with in the destination country, far from the origin of the product. The utilization of waste into useful raw materials and products is an essential principle in industrial ecology. However, the practice of dumping fish waste at sea, which is commonly done by factory freezer trawlers, can be considered a way of reducing the environmental impact of the waste. This is the same principle used when chipping branches and bark in the forest and spreading it to recycle some of the nutrients. Since the fish waste is a source of nutrient for life in the ocean, it is recycled locally which also reduces the total volumes to be transported to land. The principle of processing the waste locally, before it is transported, should also be adhered to when considering the environmental aspects of fresh whole fish transport vs. processed (frozen, dried, smoked) fish. The proximity principle, which states that the products should be produced close to the customer, is highly applicable in this context. If the proximity principle is not adhered to, more transport is generated, resulting in more negative environmental effects. These are principles that should be applied within the industrial ecology framework.

Finally, a discussion of the advantages of using industrial ecology as a framework for the analysis of energy use in production chains might be of value for the understanding of the major issues in this article. As pointed to in the introduction, both life cycle analysis and life cycle assessment are important tools within the wider conceptual frame of industrial ecology. Both LCA-based methodology and industrial ecology analysis can give important data for energy use along production chains. There are however major differences between the two approaches. LCA is a much more limited approach than industrial ecology. LCA can give data on the environmental impacts such as energy use, but industrial ecology goes much further, and points in addition to implications for products and production processes, within the industrial systems. Two major implications are pointed out in this article. They are the implications for the form the fish product is in during transport (less whole fresh, more processed such as frozen, dried or smoked) and implications for transport mode (less air and road, more rail and sea).

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5. Transport Scenarios in a Company Strategy[29]

5.1. Abstract

The environmental company strategy of the case company Oslo Sporveier[30] includes scenarios for the development of person transport in Oslo up to year 2016. The basis for three different scenarios is described. This paper presents the use of scenarios as background for environmental reporting. Emissions, energy, land and time use from person transport in the three different scenarios were determined. The scenarios were: 1) a private car scenario, where the main growth in person transport is to be met with a strong increase in the use of private cars, 2) a public transport scenario, where the increase in person transport is to be taken care of with a strong increase in the public transport, and 3) the sustainability scenario, with a reduction in total person transport, increased share of public transport and walking/bicycling, and reduced share of private car use. The total energy use, CO_2-emissions, NO_X-emissions and particle emissions from person transport in Oslo are reduced in all 3 scenarios compared with the situation in 1996. The reduction is smallest in the private car scenario and largest in the sustainability scenario. The land use increases in the private car scenario and the public transport scenario, while there is a reduction in land use in the sustainability scenario. The total time consumption connected to person transport increases in all 3 scenarios.

5.2. A company strategy with scenarios as basis for environmental reporting

This is the first of two articles describing the work carried out by Western Norway Research Institute in connection with the environmental reporting from the public transport company Oslo Sporveier. This article describes scenarios for the transport development in Oslo, while the second article comprises work connected to the environmental report and the societal accounting from the company (Andersen, 2003).

Oslo Sporveier is a company that provides public transport services to a large part of Oslo's population. As a background for the environmental reporting from the company, scenarios were developed to show the environmental consequences of future growth of person transport in Oslo. The company's strategy is emphasising the importance of increasing the use of public transport relative to individual transport. By developing scenarios for different trends in the development of person transport it is possible for the company to illustrate the environmental consequences of implementing its strategy of increased share of public transport.

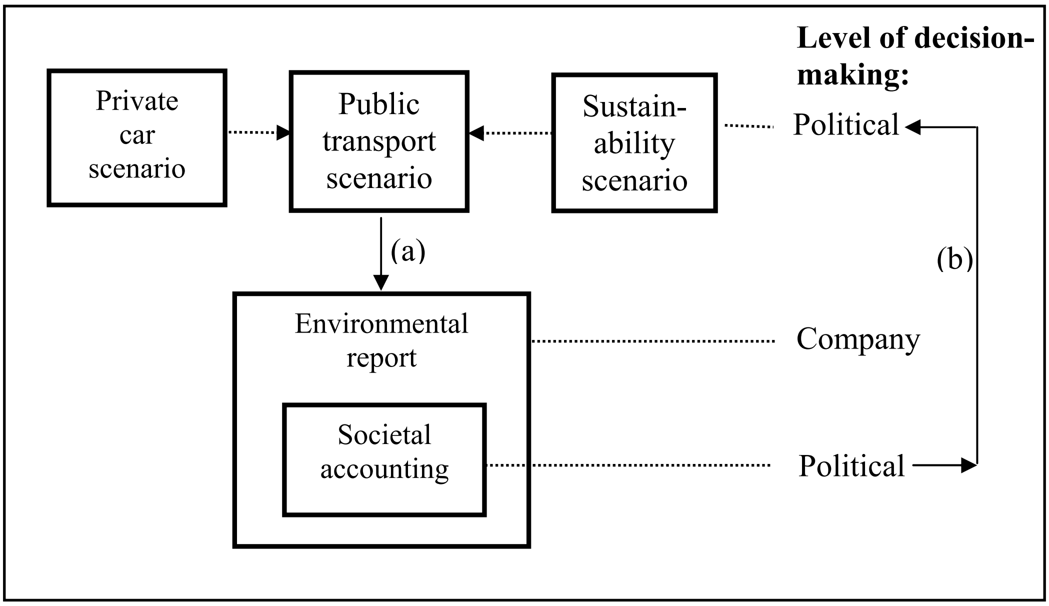
Scenarios can have elements of a political character. In the scenarios for Oslo Sporveier the environmental consequences of future growth in public transport are

[29] Hans-Einar Lundli, Erling Holden and Karl Georg Høyer, all at Western Norway Research Institute, are co-authors on this article.
[30] The full name of the company is Oslo's Public Transportation Company Ltd or AS Oslo Sporveier (in Norwegian). The shorter name Oslo Sporveier is used throughout this article.

compared with growth in individual transport. This is important knowledge for guiding the decision-makers in the development of a city. As part of its business strategy, the company therefore has, in collaboration with Western Norway Research Institute, made three scenarios for development of person transport in the city Oslo towards the year 2016 (Høyer et al., 1998; Lundli et al., 1998a, 1998b; Andersen, 1998).

The connection between the scenarios, the company environmental report, societal accounting, and levels of decision-making is shown in *Figure 25*.

Figure 25 *The connections between the scenarios, environmental report, societal accounting, and decision-making levels*



The scenarios, the environmental report and the societal accounting are all elements of the company strategy for Oslo Sporveier. In *Figure 25* it is illustrated that these elements provide knowledge to decision-makers at two different societal levels. This is indicated by the dotted lines in the figure. First of all, the scenarios function at a political level, in providing knowledge to political decision-makers. This is strengthening the dialogue with the city authorities, which is important in establishing the necessary framework conditions for the operations of the company.

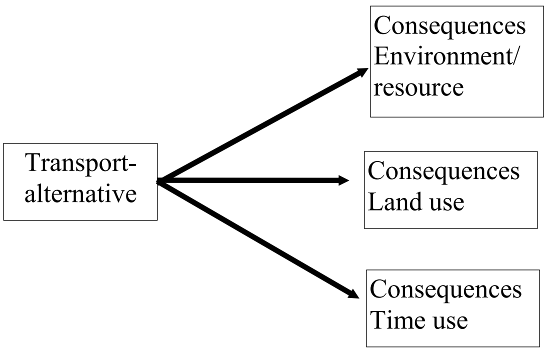
The public transport scenario is part of the company's long-term transport politics, which is based on a strong growth in public transport. In a sustainability scenario there is in addition a strong absolute reduction in the use of private cars. In addition the total mobility is reduced in the sustainability scenario. Few long-term environmental gains can be expected from an isolated focus on improving public transport. A large reduction in the private car use and the total mobility is in addition necessary for achieving a sustainable transport system. Both the private car scenario and the sustainability scenario thus give input into the public transport scenario, as indicated with dotted arrows in *Figure 25*.

The environmental report is providing knowledge for decision-making mainly at the level of the company, while the societal accounting is providing knowledge to decision-makers at the political level. The process of issuing the societal account is taking place at more frequent intervals than the updating of the scenarios; in connection with the preparation of the annual environmental report. The societal account has the function to provide knowledge to the political level through a supplement and correction to the scenarios. The solid arrow (b) in *Figure 25* indicates this. There is thus a loop of knowledge-flow between the company and the political level; from the scenarios through the environmental report (a) including the societal accounting and back to the scenarios (b).

5.3. Overall methodology

The main structure of the scenario-analysis presented in *Figure 26*.

Figure 26 *Main structure of the scenario-analysis*



The different transport alternatives (car, bus, walk etc.) have consequences in the three areas environment/resource, land use and time use. The consequence group environmental/resource is limited to *energy use*, *CO_2 emissions*, *NO_X emissions and particle (PM) emissions*. The consequence group land use is limited to *land use for traffic purposes*. The last consequence group, time use, is limited to *time consumption for person transport*.

Each transport alternative has different values for a set of fixed variables. The following main variables are used:

- Accumulated transport performed (person-kilometre / year)
- Distribution of person transport performed by the different transport means
- Average occupancy rate for the different transport means

The study comprise of transport being conducted within the county border of Oslo[31]. The following transport means are included in the analysis: walk, bicycle, private car, taxi, bus, tram and metro.

[31] Statistical office of City of Oslo have made prognosis for growth in population up to year 2005. In addition data from Statistics Norway was applied for making an estimate for the growth in the population of Oslo from 488 659 in 1996 to 595 500 in 2016.

5.4. The person transport in the base year 1996

In obtaining figures for accumulated transport work many different data sources were analysed. The main sources were data from the Planning and Building department in the municipality of Oslo, which they collected in connection with their transport planning work. Upon request from Western Norway Research Institute, the Planning and Building department performed calculations based on their data material. In addition, data material from Oslo Sporveier and the Greater Oslo Local Traffic (SL), based on surveys of the person transport work carried out by their own transport means, was used. *Table 13* shows the results of the calculations of person transport work in 1996.

Table 13 *Person transport by various transport means in 1996 (million person-kilometre)*

Transport mean	**1996**	%
Walking	131	2.9
Bicycle	68	1.5
Private car[32]	3 280	73.8
Taxi[33]	160	3.6
Bus[34]	253	5.7
Train[35]	173	3.9
Tram[36]	87	2.0
Metro	294	6.6
Total	**4 446**	100.0

Some comments to the methodology for calculating the person transport work for 1996 can be made:

- The figures apply to the total traffic in 1996, that is, weekend and holiday traffic is included
- The figures for walking and bicycle are estimated on the basis of data from the travel patterns survey for the Oslo area in 1990 and comprise only Oslo citizens.
- The person transport work by private car includes all driving on the roads in Oslo, regardless of where the travel starts and ends. The Planning and Building department in the municipality of Oslo estimated the number of

[32] The calculations are based on an occupancy rate of private cars in Oslo to 1.6 persons per vehicle. This was based on counting made at the toll ring in Oslo, travel pattern survey for Oslo in 1990 and the private car survey made by Statistics Norway in 1995.
[33] The calculations are based on an estimate of an occupancy rate of 1.3 passengers per taxi, based on previous studies.
[34] An occupancy rate of 13.5 passengers per bus is applied, based on previous analyses.
[35] An occupancy rate of 32% is applied in the calculations. This is based on empirical data for local- and intercity train traffic in Oslo (Høyer & Heiberg, 1993)
[36] An occupancy rate of 16% for tram and metro, based on analyses performed by Oslo Sporveier, was used.

vehicle-kilometres carried out by private car, based on traffic counting made at various locations in Oslo.
- The taxi figure was estimated on the basis of statistical material from Oslo Taxi (www.oslotaxi.no).
- The train figure includes travels with SL starting in Akershus[37] and ending in Oslo. Travels starting in Oslo and ending in Akershus are registered on Akershus.
- The bus figures for Oslo comprise the bus services of Oslo Sporveier including contract driving and SL. Like the train figures, the bus travels starting in Akershus and ending in Oslo are registered on Oslo. Other type of bus transport in Oslo such as the bus to the airport and long-distance express coaches to and from Oslo are not included.

In *Table 13* it can be seen that private car (including taxi) accounts for approx. ¾ of the person transport work in Oslo. The public transport means account for less than 20% of the total transport work, while walking and bicycle together constitute less than 5%.

If we take a look at the distribution of number of journeys made with the various means, the picture is somewhat different (*Table 14*).

Table 14 *Number of journeys in 1996*

Transport mean	Number of journeys (million)	%
Walking	147	25.8
Bicycle	44	7.7
Private car	219	38.5
Taxi	15	2.6
Bus	48	8.4
Train	9	1.6
Tram	32	5.6
Metro	56	9.8
Total	**569**	100.0

More than 41% of all the journeys in Oslo are carried out with private car or taxi, 25% by public transport and 34% by walking/bicycle. The reason why private cars still carry out as much as 75% of the total transport work is that the length of the car journeys in average are longer than the journeys by public transport and by walking/bicycle.

Table 14 is based on assumptions of average lengths per journey for various transport means. These are shown in *Table 15*.

[37] Akershus is the neighbouring county of Oslo to the west, south and east

***Table 15** Average lengths per journey for various transport means in 1996*

Transport mean	Length of journey (km)
Walking	0.9
Bicycle	1.5
Private car	15.0
Taxi	10.7
Bus	5.2
Train	20.4
Tram	2.7
Metro	5.2

The average length of journeys by private car is estimated with basis in the travel pattern survey for Oslo and Akershus (Vibe, 1991). Here the average journey for private cars on weekdays was estimated to 12.0 km for driver and 14.6 for passenger. Since we are interested in the lengths on all days, not only weekdays, a somewhat higher average length is assumed (15.0 km). The average length of journeys by bus, train, tram and metro was obtained from Oslo Sporveier and SL. The journey length for bus is a weighted average of the bus transport of Oslo Sporveier and SL's commuting buses. The average length of taxi trips is based on statistics from Oslo Taxi. The length of walk and bicycle trips is determined with the use of the numbers for person-kilometres and number of journeys[38].

5.5. Person transport development in the scenarios for 2016

5.5.1. The private car scenario

The private car scenario is not compatible with the company strategy. In this scenario it is assumed that all growth in the person transport in Oslo up to the year 2016 will be taken care of by private car or taxi. The scenario is based on a 1.9% annual increase in the total person transport work, a 1.1% annual increase in the person transport work for private car and a 1.7% annual increase for taxi in the period 1996-2016. The projected growth in the person transport work carried out by private car and taxi is based on county prognoses given in the "Veileder" (the Guide) no. 4 of the national road and road traffic plan (NVVP) for the period 1998-2007. These prognoses have been adjusted for updated population growth prognoses made by Statistics Norway. It is assumed that the growth in person transport work in terms of vehicle-kilometres will be just as high for taxis as for private cars. However, the occupancy rate[39] is assumed to be lowered for private cars, but remain constant for taxis, resulting in a higher percentage increase in person transport work (in terms of person kilometres) for taxi then for private cars.

[38] The number of walk- and bicycle journeys in 1996 was determined with the basis in the travel pattern surveys carried out by Oslo Sporveier. Here the number of journeys was estimated to 1.3 per day for walk and bicycle (for persons above 15 years old).

[39] The occupancy rates for various transport means in the private car scenario are assumed to be the same as in 1996, except the lowering from 1.6 to 1.4 persons per car.

The various public transport means and walking/bicycle will carry out the same amount of person transport in 2016 as in 1996. The public transport's share of the total amount of person transport in Oslo will therefore be reduced towards the year 2016 in the private car scenario.

In this scenario it is presupposed a continuation of today's development in terms of land use patterns in the Oslo region, with a continued tendency to urban sprawl, as well as a sub-urbanisation on a regional level. This stems from a continuation of the policies of expanding the road system and a relatively unrestrictive parking policy.

5.5.2. The public transport scenario

Of the three scenarios it is the public transport scenario that is within the framework of the company strategy. This scenario is based on a precondition that in the year 2016 there is a situation in which 1/3 of individuals' journeys are carried out by public transport, 1/3 by private car, and 1/3 on foot or by bicycle[40].

The total person transport work in the public transport scenario 2016 is assumed to be the same as in the private car scenario[41]. Within public transport, the share of usage for each of the means remains constant. The same is assumed for the share between bicycling and walking. These preconditions gives annual increases in the person transport work by 0.3% for private car and taxi, 1.3% for walking and bicycle, and 2.7% for bus, train, tram and metro, in the period 1996-2016.

Generally, this scenario is based on a precondition of a major increase in services for public transport. This implies an effort to establish new public transport nodes through land use planning, with emphasis on co-localisation of bus and rail. In order to avoid congestion of central streets, nodes will be built where a fast transfer can occur, between the commuting buses using the main arteries into/from Oslo and the public transport network in Oslo. Furthermore, it is presupposed that a "combined rail" system will be built. This is based on carriage material which can be used on the national rail tracks as well as on the tram and metro lines of Oslo Sporveier[42]. The introduction of a combined rail system will reduce the need for a major expansion of the bus system[43].

It is presupposed that a strong effort is made in the construction of pedestrian and bicycle lanes, with emphasis on ensuring walking and bicycle access to important public transport nodes and stops.

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[40] This distribution of person travels is approximately equal to the present situation in Copenhagen (Eir, 1997).

[41] The estimation of the transport work in the public transport scenario is based on occupancy rates as in 1996, except the lowering from 1.6 to 1.4 persons per car, increase from 13.5 to 20 passengers per bus, increase from 32% to 38% for train, and increase from 16% to 22% for tram and taxi. Based on empirical data from other large cities there is no basis for applying a larger average capacity utilisation than 20 passengers per bus. The assessments of the potentials for increases in occupancy rates for tram and metro are based on previous analyses by Western Norway Research Institute (Høyer & Heiberg, 1993).

[42] Oslo Sporveier operates all the tram and metro lines in Oslo.

[43] On the other hand, we have no basis for assuming how large a share of the bus traffic that can be transferred to a combined rail.

5.5.3. The sustainability scenario

The sustainability scenario for 2016 is used to illustrate the consequences if Oslo will achieve a sustainable transport system by the year 2050. In a sustainable transport system in a major city, the inhabitants can get their mobility needs satisfied through a well functioning public transport system in combination with the pedestrian and bicycle lanes. The person transport in 2016 is estimated by assuming a linear development rate for the period 1996-2050, with basis in population growth estimates from Statistics Norway[44]. The sustainability scenario presupposes a significant reduction in the total mobility per inhabitant[45].

The person transport work carried out by public transport means is assumed to be the same in the sustainability scenario as in the public transport scenario. The average transport work by walking per inhabitant in Oslo will be almost doubled from 0.73 km per day in 1996 to 1.5 km per day in 2050. The bicycle use will increase from 0.38 km per day in 1996 to 2.0 km per day in 2050. As a comparison, the inhabitants in Denmark bicycled on the average 1.5 km per day in 1994[46].

The main difference between the public transport and the sustainability scenarios is that the sustainability scenario is based on the implementation of a number of policy measures to reduce the private car-based mobility. It is presupposed that stringent policy measures within land-use planning, which direct key societal functions towards the centre of Oslo, are implemented. This includes a complete termination of the practice of establishing car-based shopping centres on the outskirts of Oslo. In addition, it is presupposed the same land use policies regarding transport nodes as in the public transport scenario.

A restrictive parking policy is presupposed. This will mean a gradual closing-down of central car-parks and parking areas connected to major workplace locations. The scenario is based on new forms of land use policy in relation to existing transport infrastructure (mainly roads and car parks). Instead of building special pedestrian and bicycle lanes, sections of the existing road system are being reserved for bicycles. Similarly, a significant priority of buses in special lanes for all important transport arteries is presupposed. Furthermore, the scenario assumes a major increase in the extent of car-free zones. It is also presupposed that parts of the existing areas of road-transport infrastructure are replaced with buildings. This

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[44] The estimation of the transport work in the sustainable transport scenario is based on occupancy rates the same as in 1996, except increases from 13.5 to 20 passengers per bus, from 32% to 40% for train, and from 16% to 25% for tram and taxi.

[45] In 1995, the person mobility in Norway was approx. 35 km per day per inhabitant, excluding walking and bicycling (Høyer, 2000). In other works we have estimated a level of "sustainable mobility" in the Nordic countries for 2050. In these studies we have arrived at a mobility of 16 km per day per inhabitant in 2050, excluding walking and bicycling. Oslo (and other major cities) must take a larger share of the reduction in mobility than the rural areas. This implies that the mobility per day per inhabitant must be lower than 16 km in 2050. Our data material suggests that the total mobility level per inhabitant in Oslo in 2050 must be lowered to 11 km per day (excluding walking and bicycling).

[46] Denmark and Holland have a significantly higher bicycle usage per inhabitant than any other country in Europe.

is particularly the case for parking areas and parts of the road areas in the centre of the city.

The policy measures to ensure improved services for bus and rail transport in the public transport scenario are also presupposed in the sustainability scenario.

5.5.4. *Comparison of person transport in the scenarios*

Table 16 shows the predicted transport work to be performed by various transport means in the three scenarios for the year 2016.

Table 16 *Person transport by various transport means in three scenarios for 2016 (million person-kilometre, percent)*

Transport Mean	**Private car scenario 2016**	%	**Public transport scenario 2016**	%	**Sustainability scenario 2016**	%
Walking	131	2.5	171	3.2	241	6.0
Bicycle	68	1.3	89	1.7	254	6.3
Private car	4 096	76.9	3 505	65.8	2 065	51.0
Taxi	222	4.2	171	3.2	101	2.5
Bus	253	4.8	438	8.2	438	10.8
Train	173	3.2	300	5.6	300	7.4
Tram	87	1.6	147	2.8	147	3.6
Metro	294	5.5	504	9.5	504	12.4
Total	**5 324**	100.0	**5 324**	100.0	**4 049**	100.0

In comparison with the person transport work in 1996 (*Table 13*) we see from *Table 16* that the total person transport increases by 20% in the period 1996-2016 in both the private car and the public transport scenario. In the sustainability scenario it is reduced by 9%.

The person transport in the three scenarios for 2016 is also shown in terms of the number of journeys[47] made by each transport mean (*Table 17*).

[47] The calculation of number of journeys made in each scenario was based on the assumption that average travel distance for the various transport means is the same as in 1996 (as shown in *Table 15*).

Table 17 *Number of journeys in the three scenarios (million journeys, percent)*

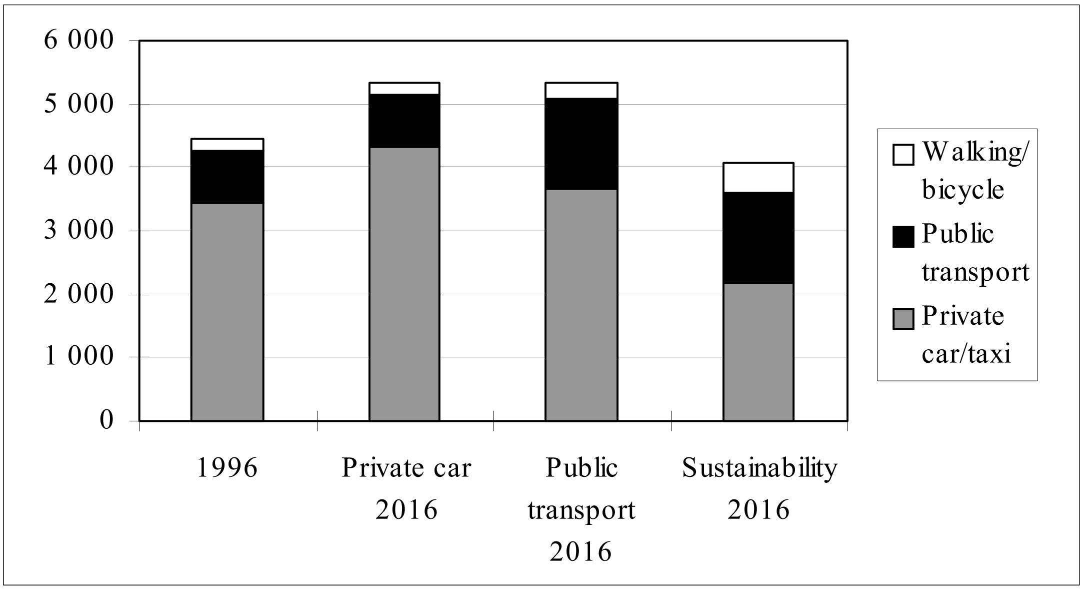
Transport Mean	**Private car scenario 2016**	%	**Public transport scenario 2016**	%	**Sustainability scenario 2016**	%
Walking	147	21.2	192	25.6	271	32.6
Bicycle	44	6.3	57	7.6	165	19.8
Private car	337	48.6	234	31.2	138	16.6
Taxi	21	3.0	16	2.1	9	1.1
Bus	48	6.9	84	11.2	84	10.1
Train	9	1.3	15	2.0	15	1.8
Tram	32	4.6	54	7.2	54	6.5
Metro	56	8.1	97	13.0	97	11.7
Total	**694**	100.0	**749**	100.0	**832**	100.0

The transport means can be summarised into three main categories of transport modes:

- Walking/bicycle
- Public transport
- Private car/taxi

The development of the person transport for these three main categories of transport modes in the scenarios is shown in *Figure 27*.

Figure 27 *Transport work of main categories of transport modes in 1996 and the three scenarios for 2016 (million person-kilometre)*



The share of private car (including taxi) of the total person transport work in Oslo will increase from 77% in 1996 to 81% in 2016 in the private car scenario. The private car scenario implies a decline in the public transport share from 19 to 15% of the total person transport work. The public transport scenario implies an opposite development: the share of the private car of the total person transport work falls to 69% in 2016, whereas the share of public transport increases to 27%. The sustainability scenario gives an even more substantial decline in the use of private cars than the public transport scenario. In the former scenario, the private car accounts for 53% of the person transport work, whereas the public transport means has increased its share to as much as 35%. The sustainability scenario implies a significant growth in the transport work carried out by walking and bicycle, and in 2016, 12% of the person transport work is carried out this way.

5.6. Energy use

The energy use linked to person transport has three main components:

1. Direct energy use:	Energy used for the propulsion of the transport means.
2. Gross direct energy use:	Direct energy use plus the energy use taking place at all stages from production of energy source to distribution of processed fuel.
3. Indirect energy use:	Energy used to produce and maintain the transport means and their infrastructure.

The energy use factors[48] applied in the calculations are shown in *Table 18*.

[48] The factors for direct energy use in 1996 are based on those used by Statistics Norway (Holtskog & Rypdal, 1997). These factors are for national averages, and have been adjusted to city-factors by applying data on energy use in different driving patterns from the National Pollution Control Agency (SFT, 1993).
For petrol-fuelled vehicles a density-factor of 0.74 kg/l and a factor for energy-content of 12.2 kWh/kg is applied, while for diesel-vehicles the density-factor of 0.84 kg/l and energy-content of 11.97 kWh/kg is used. The figures for energy use are obtained through a weighed average based on the ratio of vehicles fuelled by petrol and diesel. It is assumed that this ratio kept constant up to 2016 in the three scenarios.
The factors for gross direct and indirect energy use have their basis in previous analyses by Western Norway Research Institute (Høyer & Heiberg, 1993).

***Table 18** Energy use factors applied (kWh per person-kilometre)*

Transport mean/energy component		**1996**	**Private car scenario 2016**	**Public transport scenario 2016**	**Sustainability scenario 2016**
Private car[49]	-Direct	0.72	0.53	0.53	0.46
	-Gross direct	0.13	0.10	0.10	0.08
	-Indirect	0.10	0.07	0.07	0.06
Taxi[50]	-Direct	0.79	0.52	0.52	0.52
	-Gross direct	0.12	0.08	0.08	0.08
	-Indirect	0.13	0.10	0.10	0.10
Bus[51]	-Direct	0.35	0.31	0.21	0.21
	-Gross direct	0.04	0.04	0.02	0.02
	-Indirect	0.08	0.05	0.03	0.03
Train[52]	-Direct	0.17	0.13	0.11	0.10
	-Gross direct	0.03	0.03	0.02	0.02
	-Indirect	0.08	0.08	0.07	0.06
Tram[53]	-Direct	0.21	0.20	0.15	0.13
	-Gross direct	0.04	0.04	0.03	0.02
	-Indirect	0.06	0.06	0.04	0.04
Metro	-Direct	0.20	0.17	0.12	0.11
	-Gross direct	0.04	0.03	0.02	0.02
	-Indirect	0.06	0.06	0.04	0.04

The results of the calculations of the direct and total (direct plus gross direct plus indirect) energy use are shown in *Figure 28*.

[49] The energy use factors are based in the assumption that the increase in energy-efficiency is the same in all three scenarios. The assumptions for reduction in fuel consumption for cars are based on estimates made by IEA (1993).

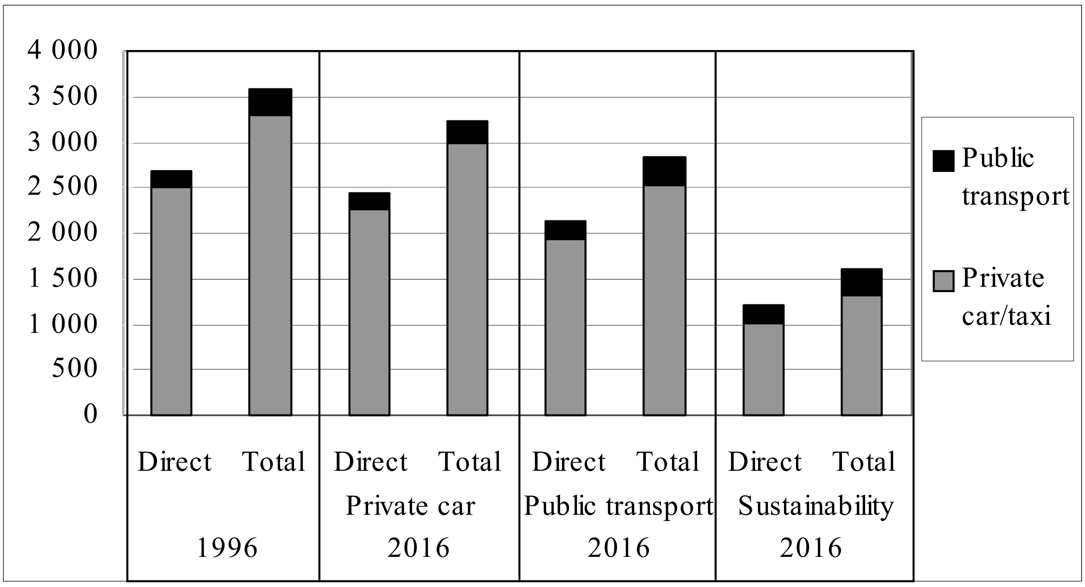
[50] Also for taxi it is assumed that the increase in energy-efficiency is the same in all three scenarios.

[51] Also for buses it is assumed that the energy-efficiency improvements are the same in the three scenarios. It is assumed that all buses use standard diesel as fuel.

[52] The energy-use factors for train are based on previous analyses by Western Norway Research Institute (Høyer & Heiberg, 1993; Vestby, 1997) and Statistics Norway (Holtskog & Rypdal, 1997). The preconditions for the energy use are the same in all three scenarios.

[53] The factors for tram and metro are equal to those used by Statistics Norway (Holtskog & Rypdal, 1997). Assessments of potentials for energy efficiency improvements are based on previous analyses by Western Norway Research Institute (Høyer & Heiberg, 1993). In all scenarios it is assumed an energy efficiency improvement for metro of approx. 10% up to 2016 and approx. 5% for tram in the same period.

Figure 28 *Energy use for 1996 and the three scenarios for 2016. Direct and total for main categories of transport means (GWh)*



Private car and taxis accounted for 92% of the energy use in 1996. Both the direct and the total energy use are expected to decrease in all three scenarios compared with the situation in 1996. This is not surprising for the public transport and the sustainability scenario, as a transition from private car to public transport in itself will lead to lower use of energy. The reason why there is also a decline in the energy use in the private car scenario is that the expected growth in the use of private cars in Oslo will be more than compensated for by improved energy efficiency of the cars.

The total energy use in 2016 compared with 1996 will be reduced by 9% in the private car scenario, 20% in the public transport scenario, and as much as 55% in the sustainability scenario.

In the public transport and sustainability scenarios there will be no decline in the energy use for public transport. This is caused by the significant growth in the person transport work by public transport means in these two scenarios, as a consequence of the transition from private car.

5.7. CO_2 emissions

In the same way as for energy use, the total emissions of CO_2 from person transport consist of three main components: direct CO_2 emissions, gross direct CO_2 emissions, and indirect CO_2 emissions. The factors for CO_2 emissions[54] applied in the calculations are shown in *Table 19*.

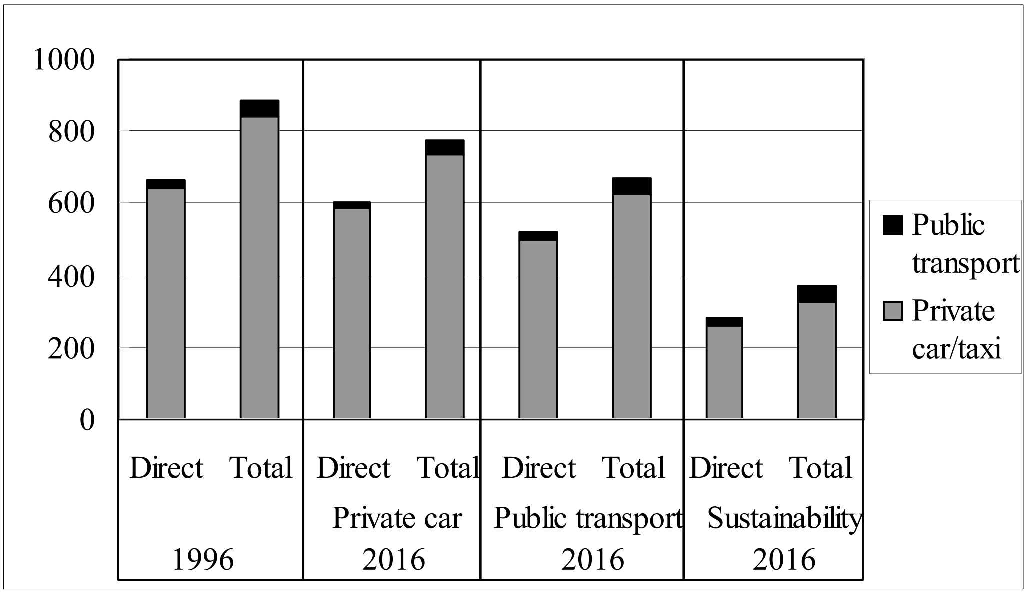
[54] The calculations of direct CO_2 emissions for cars, taxis and buses are based on the previously presented factors for direct energy use. The conversion-factors for CO_2 – content of 3.13 kg CO_2 per kg petrol and 3.17 kg CO_2 per kg diesel are used in the calculations. Rail-based transport (train, tram and metro) in Oslo is all electrified, and thus have no direct CO_2 emissions. The factors for gross direct and indirect CO_2 emissions have their basis in the study by Høyer & Heiberg (1993).

Table 19 *Factors for CO_2 emissions applied (gram CO_2 per person-kilometre)*

Transport mean/ emission component		**1996**	**Private car scenario 2016**	**Public transport scenario 2016**	**Sustainability scenario 2016**
Private car	-Direct	185	135	135	118
	-Gross direct	33	24	24	21
	-Indirect	24	11	11	10
Taxi	-Direct	208	136	136	136
	-Gross direct	31	20	20	20
	-Indirect	33	17	17	17
Bus	-Direct	94	83	56	56
	-Gross direct	11	10	7	7
	-Indirect	18	10	7	7
Train	-Direct	0	0	0	0
	-Gross direct	13	10	8	8
	-Indirect	14	9	8	7
Tram	-Direct	0	0	0	0
	-Gross direct	14	14	10	9
	-Indirect	14	9	7	6
Metro	-Direct	0	0	0	0
	-Gross direct	14	14	10	9
	-Indirect	14	9	7	6

The results of the calculation of the direct and total (direct plus gross direct plus indirect) CO_2 emissions are shown in *Figure 29*.

Figure 29 *Emissions of CO_2 for 1996 and the three scenarios. Direct and total for main categories of transport means (1000 tonnes)*



In 1996, private cars and taxi accounted for as much as 95% of the total CO_2 emissions from person transport in Oslo. In the private car scenario the total emission of CO_2 from person transport in Oslo will be reduced by 13% in 2016 compared with 1996. In other words, improved energy efficiency will more than compensate for the increased use of private car in the private car scenario. The public transport and sustainability scenario will give an even stronger reduction of the CO_2 emissions. These two scenarios will give a total CO_2 reduction of 24% and 58% respectively.

5.8. NO_x emissions

The total emissions of NO_x also consist of three main components: direct NO_x emissions, gross direct NO_x emissions, and indirect NO_x emissions. The factors for NO_x emissions[55] applied in the calculations are shown in *Table 20*.

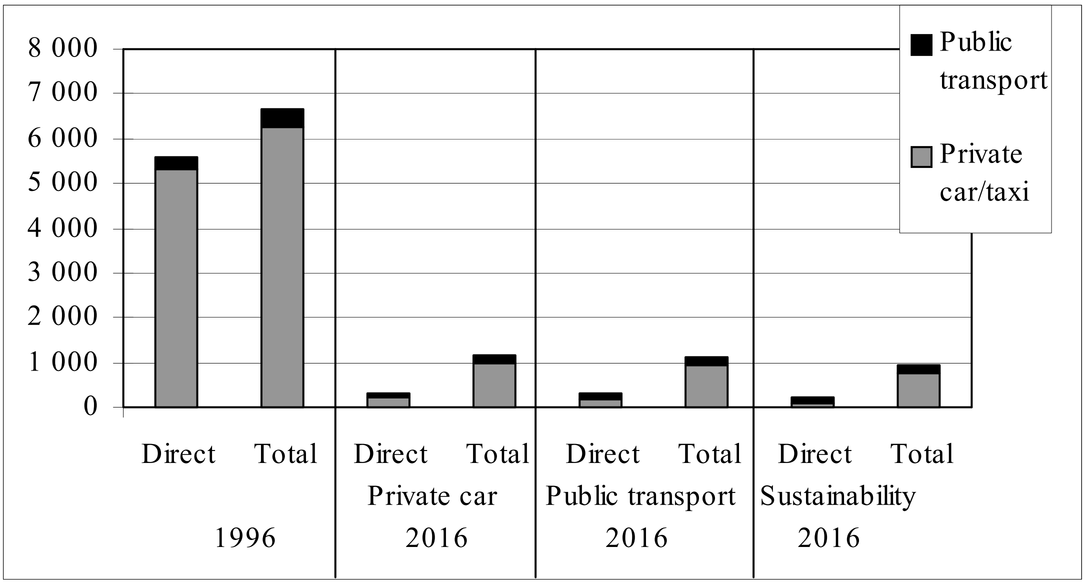
***Table 20** Factors for NO_x emissions applied (milligram NO_x per person-kilometre)*

Transport mean/ emission component		**1996**	**Private car scenario 2016**	**Public transport scenario 2016**	**Sustainability scenario 2016**
Private car	-Direct	1587	50	50	44
	-Gross direct	170	120	120	105
	-Indirect	110	55	55	48
Taxi	-Direct	669	62	62	62
	-Gross direct	160	110	110	110
	-Indirect	100	50	50	50
Bus	-Direct	1160	400	270	270
	-Gross direct	90	70	47	47
	-Indirect	70	50	34	23
Train	-Direct	0	0	0	0
	-Gross direct	41	30	25	24
	-Indirect	60	40	34	27
Tram	-Direct	0	0	0	0
	-Gross direct	65	50	36	32
	-Indirect	50	30	22	14
Metro	-Direct	0	0	0	0
	-Gross direct	65	50	36	32
	-Indirect	50	30	22	14

The calculated direct and total (direct plus gross direct plus indirect) emissions of NO_x from person transport in Oslo are shown in *Figure 30*.

[55] The factors for direct NO_x emissions in 1996 are based on those used by Statistics Norway (Holtskog & Rypdal, 1997). These factors for national averages have been adjusted to city-factors by applying data on different driving patterns from the National Pollution Control Agency (SFT, 1993). Factors for direct NO_x emissions in 2016 are based on the assumption that all cars, taxis and buses comply with the EURO IV standard. The factors for gross direct and indirect NO_x emissions have their basis in the study by Høyer & Heiberg (1993).

***Figure 30** Emissions of NO_x for 1996 and the three scenarios. Direct and total for main categories of transport means (1000 tonnes)*



Private car and taxis accounted for 95% of the NO_x emissions in 1996. For all three scenarios there is a considerable reduction (94-96%) in the direct emissions of NO_x up to the year 2016. Technological development coupled with gradually more stringent regulations on NO_x emissions from vehicles (particularly for private cars) will contribute to this development.

5.9. Particle emissions

The calculation of emission of particles is limited to the direct emissions of PM_{10} and $PM_{2.5.}$ Gross direct and indirect emissions of particles are not included due to the large uncertainties connected to the quantification of these components of the total particle emissions. In this analysis five main processes responsible for generation of particles are included:

1. Emissions from exhaust[56]
2. Wear of pavement[57]
3. Wear of tyres[58]
4. Wear of brakes[59]
5. Grinding of larger particles with subsequent re-suspension in the air[60]

[56] The factors for calculations of particles from exhaust in 1996 are based on those used by Statistics Norway (Holtskog & Rypdal, 1997)

[57] The calculations of PM_{10} and $PM_{2.5}$ from wear of pavement, mainly from the use of studded tyres, have basis in several Norwegian studies (Larssen, 1987; Vegdirektoratet, 1997; SINTEF, 1994; Larssen, 1997; Anda & Larsen, 1982).

[58] The calculations of emissions of PM_{10} and $PM_{2.5}$ caused by wear of tyres, i.e. particles originating from the tyres, have basis in estimations made by California Air Resources Board (CARB, 1979; Gaffney, 1998).

[59] Determination of particle-generation from wear of brake linings are also based in estimations made by California Air Resources Board (CARB, 1979; Gaffney, 1998 and CARB, 1998).

[60] The calculations of PM_{10} and $PM_{2.5}$ from grinding of larger particles with subsequent re-suspension in the air have basis in estimates made by Norwegian Institute for Air Research (Larssen, 1987).

The calculations cover particle emissions from bus, private cars and taxis. Emission of particles from rail transport is not included, as this mainly is connected to diesel-trains. Because the rail transport in the Oslo-region is electrified, these emissions can be neglected.

The factors for emission of PM_{10} and $PM_{2.5}$ applied in the calculations are shown in *Table 21.*

Table 21 *Average PM_{10} and $PM_{2,5}$ emissions in 1996 and 2016 (milligram per vehicle-kilometre)*

Transport mean/source		**1996**		**2016**	
		PM_{10}	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}$**
Private car:	Exhaust[61]	47.6	46.4	5.4	5.2
	Wear of pavement	81.5	40.7	37.0	18.5
	Wear of tyres	52.3	41.9	52.3	41.9
	Wear of brakes	24.3	19.4	24.3	19.4
	Grinding and re-suspension	35.5	17.7	8.9	4.4
Taxi:	Exhaust[62]	129.4	117.7	17.8	16.2
	Wear of pavement	81.5	40.7	37.0	18.5
	Wear of tyres	52.3	41.9	52.3	41.9
	Wear of brakes	24.3	19.4	24.3	19.4
	Grinding and re-suspension	17.7	8.9	4.4	2.2
Bus:	Exhaust[63]	1034.3	930.9	122.2	110.0
	Wear of pavement	88.9	44.4	88.9	44.4
	Wear of tyres	120.4	96.3	120.4	96.3
	Wear of brakes	130.4	104.3	130.4	104.3
	Grinding and re-suspension	141.8	70.9	35.5	17.7

The results of the calculations of $PM_{2.5}$ in 1996 and the three scenarios are shown in *Figure 31*, while the PM_{10} results are shown in *Figure 32*.

[61] The bases for the calculations of emissions of PM10 and PM2.5 in the exhaust of petrol-fuelled cars in 2016 are estimates on U.S. national averages made by CARB (CARB, 1998). These have been adjusted to be applicable for city-driving in Norway with the use of data on driving patterns from the National Pollution Control Agency (SFT, 1993). For calculation of emissions of PM_{10} and $PM_{2.5}$ in the exhaust of diesel-fuelled cars in 2016, it is assumed that all cars comply with the EURO IV standards.

[62] The factors for taxis have basis in the same works as for private cars, but adjusted for a higher share of diesel-fuelled vehicles.

[63] The factors for PM_{10} and $PM_{2.5}$ in the exhaust from buses in 2016 are based on compliance with the EURO IV standards.

Figure 31 *Emission of $PM_{2.5}$ for main categories of transport means in 1996 and in the three scenarios (tonnes)*

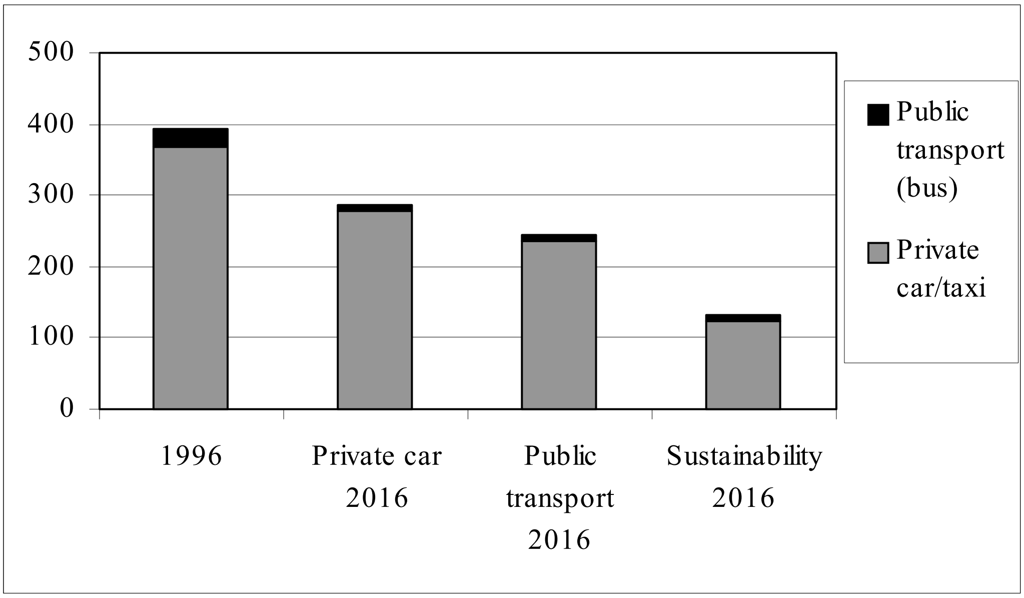
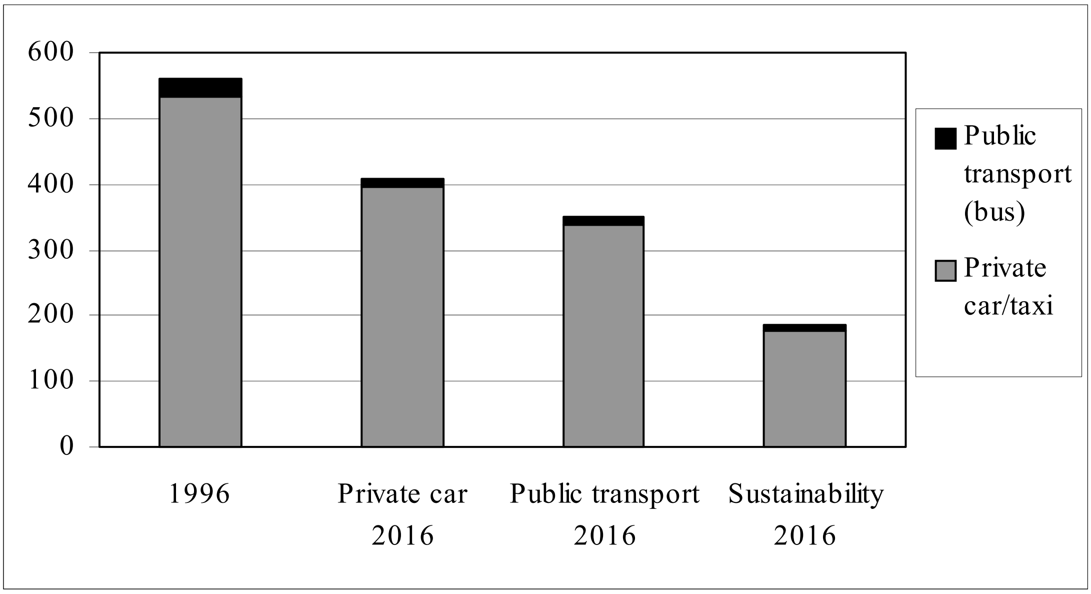


Figure 32 *Emission of PM_{10} for main categories of transport means in 1996 and in the three scenarios (tonnes)*



Private car and taxis accounted for 95% of the particle emissions in 1996. The total emissions of $PM_{2.5}$ and PM_{10} from person transport in Oslo will be reduced in all 3 scenarios compared with 1996. Technological development in combination with political measures and more stringent regulations on particle emissions will contribute to this development. The reduction is smallest in the private car scenario, and largest in the sustainability scenario.

5.10. Land use consequences of the scenarios

A considerable land use is connected to the transport sector. Land use serves as an indicator for land-linked environmental problems, such as reduction of biological diversity, closing-down of valuable production areas and cultural landscapes, as well as conflicts in relation to other user interests for these land areas. In the analysis it is distinguished between two different types of land use:

1. Direct land use:
   - Transport artery (road and rail)
   - Stations (bus stops, railway stations etc.)

2. Indirect land use
   - Land tied up to other land use as a consequence of transport activities (e.g. building-restriction zones along roads)
   - Car parks and other types of parking grounds
   - Land use linked to offices, workshops, etc. for the transport mode
   - Land use linked to production and distribution of energy (e.g. transmission lines and water reservoirs for electricity consumption, petrol stations, etc.)
   - Land use linked to maintenance and distribution of transport means (e.g. workshops and car dealers)

This analysis covers direct land use and limited indirect land use. The indirect land use is limited to include land areas for car parks and petrol station premises, terminals, and depots.

As a basis for the calculations, the estimates[64] of land use for various transport purposes shown in *Table 22* were used.

***Table 22** Estimates of land use for various transport purposes in Oslo*

Type of land use	**Size (1000 m^2)**
Road[65] + parking areas	17 000
Parking	6 790
Seaport	1 100
Railroad, tram, metro (including stations, terminals and depots)	3 200

Private cars, taxis and bus all use the same land. For the calculations, the total size of the land use for road was distributed on each of these transport means based in the vehicle-kilometres and the relative size of the transport means.

[64] The calculations are based on rough estimates of total area for traffic purposes in Oslo made by the Planning and Building department of Oslo Municipality. This is supplemented with a mapping made in 1991/1992 of the total parkering space within the central areas of Oslo (Plan- og bygningsetaten, 1992). Additional data was obtained from Oslo Sporveier, making it possible to calculate the direct land use for tram and metro.

[65] The road area is calculated with basis in road lengths and widths from the database of Statens kartverk (Statistics Norway, 1997).

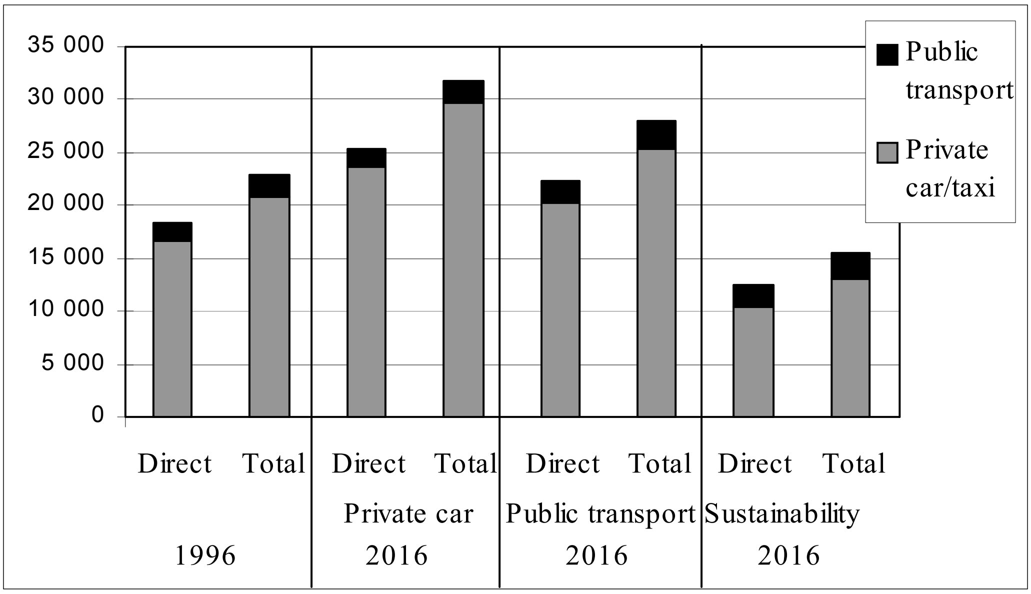
In 1996 the total length of tramlines was 40 kilometres. Almost all of this is double-tracks having a width of 6.3 metres. This gives a direct land use of 252 000 m^2. Private cars, taxis and bus, also use about 40 percent of this, but in the calculations this part of the streets is considered exclusively for tram use.

The total length of metro in 1996 was 78 kilometres. The whole length is double tracks with an average length having a width of 10.4 metre. This gives a direct land use of 811 000 m^2. About 15 kilometre of the metro is in tunnel. The metro thus have a direct land use of on the surface of 657 000 m^2.

The rail net for trains in Oslo is used both for local, regional and international trains. However, insufficient data was available for estimating the direct land use of each train type. Instead the calculations are based on a presumption that the land use for per person-kilometre of the local trains is similar to the land use for metro. This gives a direct land use of 388 000 m^2 in 1996.

The results of the calculations of the direct and total (direct plus indirect) land use are shown in *Figure 33*.

Figure 33 *Direct and total land use for main categories of transport means in 1996 and in the three scenarios (1000 m^2)*



Private car/taxi accounts for the majority (87%) of land use for transport purposes in Oslo. Roads and car parks are land demanding. The total land use increases by 39% in the private car scenario and 22% in the public transport scenario. The sustainability scenario gives a reduction in the total land use of 33%, a consequence of the fact that use of private car and taxi is drastically reduced in this scenario.

5.11. Time use in the scenarios

In the analysis of time use, calculations are made for the total time that makes individual movements possible with the various transport means (including walking). The total time consists of two components: direct time spent on the travel itself, and indirect time in terms of working hours spent to earn money to pay for the total costs of the travel. The indirect time consumption also includes hours needed for tanking, maintenance and care of one's own transport means.

This methodological approach corresponds to the understanding of time consumption outlined by Ivan D. Illich in the book "Energy and Equity" (Illich, 1974). Based on the situation in USA he argues in the following way: The typical American male devotes more than 1 600 hours in a year to the car. He sits in it when it stands still and when it is moving. He parks it and searches for it at the parking lots. Han earns money that is used to pay the monthly payments on the car. Han works to pay petrol, taxes and duties, insurance, and parking fees. This way he spends four out of sixteen hours awake on the car or in the car. And this does not include time spent in hospitals, repair/maintenance shops and courtrooms, or the time in front of the car commercials on TV. The typical American male thus invests 1 600 hours to drive 12 000 km i a year: less than 8 km/h. In countries without a transport industry people manage the same, to walk wherever they want, and they spend only 3-8% of the society's time budget for transport, instead of 28% (Illich, 1974).

The factors for direct time use[66] in the calculations are shown in *Table 23.*

Table 23 *Direct time use factors*

Transport mean	Time use (minutes per journey)
Walking	11
Bicycle	15
Private car	23
Taxi	16
Bus	25
Train	51
Tram	23
Metro	24

[66] Most of the figures are from the travel pattern analysis by Oslo Sporveier in 1996 (Oslo Sporveier, 1996). These are figures that include walk- and waiting in connection with each journey with each transport mean.

Table 24 shows the *indirect* time use factors[67] applied in the calculations.

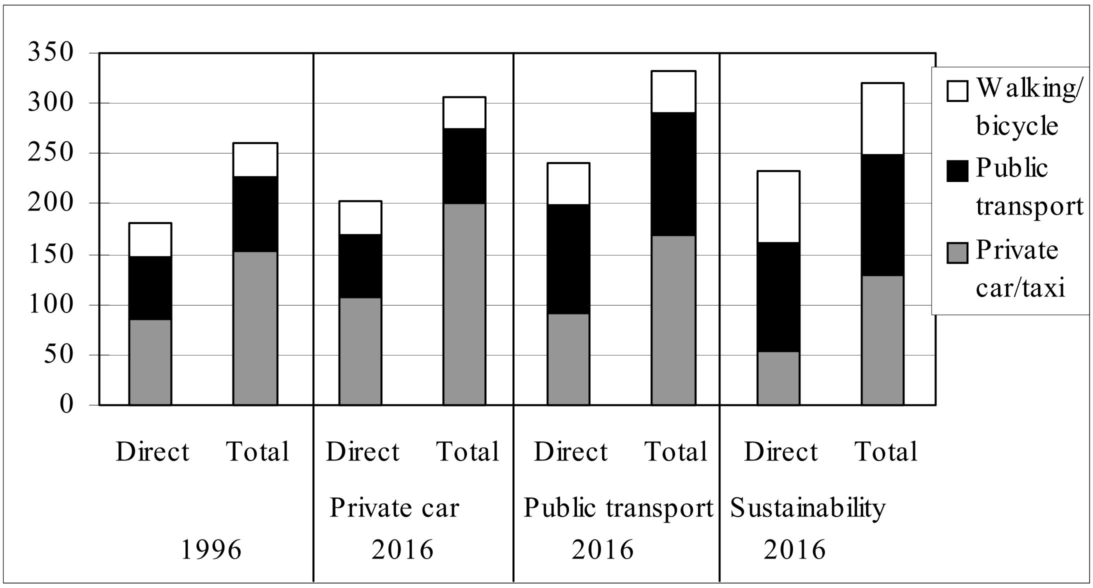
***Table 24** Indirect time use factors applied (All numbers in minutes)*

Transport mean/energy component	1996	Private car scenario 2016	Public transport scenario 2016	Sustainability scenario 2016
Walking	0	0	0	0
Bicycle[68] (per pkm)	0.3	0.3	0.3	0.3
Private car[69] (per pkm)	1.3	1.5	1.5	2.0
Taxi[70] (per pkm)	5.0	5.0	5.0	7.5
Bus[71] (per journey)	4.0	4.0	2.7	2.7
Train[71] (per journey)	6.8	6.8	5.7	5.7
Tram[71] (per journey)	4.0	4.0	2.9	2.6
Metro[71] (per journey)	4.5	4.5	3.3	2.9

The results of the calculation of the time consumption for main categories of transport means are shown in *Figure 34*.

[67] All conversions from costs in NOK to time (in minutes) are based on an average for Oslo/Akershus of NOK 120/hour, or NOK 2/minute.
[68] This is based on Åkerman (1996) and includes 0.1 minutes for maintenance and 0.2 minutes for value-depreciation, interest and repair costs.
[69] Time for own maintenance is 0.3 minutes in all scenarios. This is bases on Åkerman (1996). The total costs for ownership and usage of car (medium-size) is NOK 3,70/vehicle-kilometre. This is based on information from the national road traffic information council (Opplysningsrådet for veitrafikken, 1997). This is for 1996 and in the private car and public transport scenarios for 2016. In the sustainability scenario it is presupposed that the share of the total costs (25%) from fuel and oil will double, while the share for value-depreciation, interest and insurance (approx. 60%) will increase by 50%. This is connected to preconditions in the sustainability scenario of increases in duties on car ownership, and increase in the CO_2-taxes from NOK 0.90/kg in 1996 to NOK 3.90/kg in 2016 (based on a.o. Kågeson, 1993).
[70] The calculations of taxi costs are based on the travel fare system of Oslo Taxis. It is assumed an average of NOK 13/vehicle-kilometre in 1996 and in the private car and public transport scenarios for 2016. In the sustainability scenario it is presupposed that this cost will increase of an amount corresponding to the cost increase for private cars.
[71] The figures are based on average costs per journey, and are obtained from Oslo Sporveier and SL. In 1996 this is NOK 8 per bus journey, NOK 13.5 per train journey, NOK 8 per tram journey and NOK 9 per metro journey. These are assumed to remain constant in the private car scenario. The costs will be reduced in the public transport and the sustainability scenario corresponding to the increases in occupancy rates. It is thus presupposed that increased capacity utilisation implies increased income and correspondingly reductions in ticket prices. The public transport is assumed to be exempt from CO_2-taxes.

Figure 34 *Time consumption for the Oslo population in 1996 and the three scenarios for 2016. Direct and total for main categories of transport means (mill. hrs)*



Private car and taxis accounted for 59% of the time consumption for person transport in 1996.The total time consumption for person transport increases in all three scenarios. The lowest increase in the total of public transport and private car/taxi is found in the sustainability scenario (17%), and the highest in the private car scenario (30%).

5.12. Conclusions

This article presents the use of scenarios for different developments of person transport as part of a company strategy. The public transport scenario illustrates the environmental consequences of a development in person transport in line with the company strategy. This scenario implies a strong increase in the share of public transport use. Two other scenarios are used to illustrate other development tracks in person transport. The private car scenario is used to show the consequences of a continued increase in the private car use, while the sustainability scenario is used to illustrate the consequences of a development in person transport that follows a direction towards a sustainable transport system. The sustainability scenario is also used to draw the attention to the necessity of reducing the private car use and reducing the total mobility in addition to increase the share of public transport use.

The results showed that private car and taxis in Oslo in 1996 accounted for 77% of the person transport work, 92% of the energy use, 95% of the CO_2-emissions, 95% of the NO_X-emissions, 95% of the particle emissions, 87% of the land use and 59% of the time consumption. The total energy use, CO_2-emissions, NO_X-emissions and particle emissions from person transport in Oslo are reduced in all 3 scenarios compared with the situation in 1996. The reduction is smallest in the private car scenario and largest in the sustainability scenario. The land use increases by 39% in the private car scenario and by 22% in the public transport scenario, while there is a reduction in land use by 32% in the sustainability scenario. The total time consumption connected to person transport increases by approximately the same amount in all 3 scenarios.

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6. Environmental Reporting and Transport – the case of a Public Transport Company

6.1. Abstract

This article discusses corporate environmental reporting in the field of transport. In addition to addressing this issue in general, the article includes empirical material from a case transport company. The process of preparing the year 2000 environmental report for the company is described. The environmental report includes actions for improving the environmental performance of the company, and indicators for monitoring of the progress from year to year. This is based in separate studies of the employee's company travels, daily travel to work, and the purchasing of energy. The company is using societal accounting to show its responsibility as an important societal actor, improving the stakeholder dialogue and providing knowledge at the political level.

6.2. Introduction

This is the second of two articles describing the work carried out by Western Norway Research Institute in connection with the environmental reporting from the public transport company Oslo Sporveier. This article comprises work connected to the environmental report and the societal accounting from the company, while the first article describes scenarios for the transport development in Oslo (Andersen, 2003).

The publishing of environmental reports has become an important way for companies to communicate environmental issues with the stakeholders. A substantial amount of research has been carried out in the field of corporate environmental reporting since the first environmental reports were issued more than a decade ago (e.g. Azzone et al., 1996; Kolk, 1999; Kolk et al., 2001). Legislative requirements in many countries (e.g. the Netherlands, Sweden and Norway) for disclosure of environmental issues have contributed to the increased attention on corporate environmental reporting. In addition, a stronger societal demand for corporate transparency on environmental issues has emerged both from primary and secondary stakeholders[72].

Transport is a major consumer of energy and an important source of emissions of greenhouse gases. Transport activities are in addition an important source of the

[72] The differentiation between primary and secondary stakeholders is based on the definitions by Clarkson (1995). A primary shareholder group is "one without whose continuing participation the corporation cannot survive as a going concern", whereas secondary stakeholders are "those who influence or affect, or are influenced or affected by, the corporation, but are not engaged in transactions with the corporation and are not essential for its survival". According to such a classification, primary stakeholders are investors, employees, customers, suppliers, governments and communities. Secondary stakeholders include media and activist groups.

most serious local and regional environmental problems[73]. The problems are particularly detrimental in cities. To take a look at how well transport is included in corporate environmental reports thus becomes important. Historically the environmental reporting has focused on the production activities of the corporations. Process-energy, material use and emissions connected to the production processes and the production facilities have historically been well accounted for in the environmental reports. It is however not that common to include transport activities in the reporting. A recent study of environmental reporting in Denmark indicates that no more than a quarter of the companies include transport in their environmental reports (Holgaard and Remmen, 2001).

There are in addition many different ways to include transport in corporate environmental reporting. At least four types of transport connected to the activities of companies can be identified:

1. The movement of goods to and from a production facility. This includes the transport of raw materials into the production facilities and the distribution of finished products to the customers. For a transport company that has transport services as its main product, the amount of transport provided through the services is commonly included in the reporting. For public transport companies this encompass the person transport work of the basic transport services provided (bus, tram, metro etc.).

2. The internal transport in the company. This type of transport encompasses the person- and goods-transport within a unit and between the different 0units of the company. This is usually carried out by the company's own vehicles, but can also be performed by contracting companies.

3. Business travels. The travels made by the employees to meetings, seminars and conferences are also a type of transport work that is generated by a company's activities. This type of transport is taking place within the company's working hours and the travels often last for several days. Even so, this transport is not commonly included in corporate environmental reports.

4. Travels to work. The daily travels of the company's employees between home and the work place are even less common to include in corporate environmental reports. However, a company that provides public transport services is particularly exposed to criticism or pressure from stakeholders if the employees are not using public transport. The reporting of employee's travels to work is in addition particularly relevant for a company providing environmentally friendly transport. This is reflected in the environmental report from the case company Oslo Sporveier.

Since transport is a major consumer of energy, it is logical that energy use has a central position in the environmental reports from companies providing transport.

[73] The list of local and regional environmental problems from transport is extensive, and includes the emissions of a large number of substances with serious environmental and health effects (nitrogen oxides, particles, sulphur oxides, volatile organic compounds and others), noise, land-use demands, building corrosion and death/disabilities from traffic accidents.

Both the type and amounts of energy used are important from an environmental point of view. For companies that consume large amounts of energy in their operations, the choice of energy type and quality are important for environmental reasons. It is important for these companies to be able to document the amount of purchased energy coming from renewable sources of energy. The emission of greenhouse gases is tightly coupled to the combustion of fossil energy. Disclosing data on emissions of CO_2 and other greenhouse gases are essential elements in company environmental reports.

Corporate environmental reports are used to communicate relevant environmental issues to the stakeholders. For companies that provide public transport services, important primary stakeholder groups are the public and communities. In addition, the public transport system is important for the functioning and development of urban areas. Public transport companies thus have important societal functions. As important societal actors public transport companies have a societal responsibility. The publishing of an environmental report is one way by which the company can demonstrate this responsibility. The company can show how the environmental effects of the company's services compare with other ways of providing the service. The company can do this by disclosing its societal account. This is done in the environmental report for Oslo Sporveier for the year 2000. It is not common to include societal accounting in corporate environmental reports. But for a company that serves an important societal function, which is the case for Oslo Sporveier, it is logical to do so. The societal accounting can have the function of providing knowledge at the political level, by analysing the impact of various transport forms in the city. The societal accounting can thus complement an important function of the scenarios prepared by the company for the development of transport between 1996 and 2016 in Oslo (Andersen, 2003).

The process of preparing the environmental report for Oslo Sporveier has consisted of a long-term collaboration between the company and the researchers at Western Norway Research Institute. It started with the preparation of scenarios for the development of transport, continued with the compilation of material for the 2000 environmental report including the societal accounting, and continues on with annual environmental reporting.

6.3. The environmental report project

The company Oslo Sporveier is the largest public transport provider in Oslo, a city with approximately half a million people. The size of the public transport provided by the company is illustrated by the key figures for year 2000 in *Table 25.*

Table 25 *Key figures for Oslo Sporveier in the year 2000*

Company segment	Number of person-journeys (millions)	Number of person-kilometres (millions)	Number of lines	Total length of lines (kilometres)
Metro	68	405	5	119
Tram	35	86	11	153
Bus	54	231	62	1 387

In addition to the three transport means metro, tram and bus, the company also provides train and boat services through contracts with companies operating these transport means. Of the three main transport means provided by the company, the metro lines transport most people, while the bus route network is the most extensive in terms of number of routs and total length. The area of coverage is mainly within Oslo, but some lines also extend outside the city borders.

The composition of the vehicle fleet is shown in *Table 26*.

Table 26 *Vehicle fleet operated by Oslo Sporveier*

Vehicle type	Numbers
Metro train cars	207
Tram cars	73
Buses	303

In addition to the vehicles providing the transport services, shown in *Table 26*, the company also operates a fleet of additional vehicles for use in service and maintenance of material, infrastructure and company buildings.

Since the company's main activity is to provide transport services, the environmental effects of the transport was chosen as the superior focus in the environmental report. The report comprises all the basic transport systems, metro, tram and bus in which the company provides services. But due to the superior transport focus, other forms of transport are also included. These encompass company travels and the daily employee travel to and from work.

The project, which consisted of preparing the environmental report for Oslo Sporveier, can be considered as a case in itself, for the collaboration between a research institute and a public transport company. It has been part of a long-term collaboration between Oslo Sporveier and Western Norway Research Institute. The project was organised through a steering group and a project group in Oslo Sporveier. The steering group had the superior responsibility for the project, while the project group was responsible for the operational aspects of carrying out the project. The steering group consisted of the company-wide upper management and functioned to motivate the employees to commit time and effort to the project. The project group consisted of middle management from the operational units of the company. The following units were represented: metro, trams, buses, property, service, economy, purchasing, marketing, HSE (health, safety and environment), planning, and traffic management.

The preparation of the environmental report was a process based on a high degree of employee participation. The members of the project group collaborated closely with the researchers from Western Norway Research Institute, and made substantial efforts in assembling the necessary data material on the activities of the company. The employees participated in the identification of the critical areas and the formulation of actions for improving the environmental performance of the company.

In this article the empirical material in five main areas connected to the Oslo Sporveier environmental report for the year 2000 is presented: 1) The company's main operations, 2) Business travel, 3) Travels to work, 4) Purchasing and 5) Societal accounting.

6.4. Main company operations

The environmental impacts of the main operations of Oslo Sporveier were analysed in terms of direct energy use and emissions of CO_2, NO_x, PM_{10} and $PM_{2.5}$. Both energy in the form of electricity and the mobile and stationary combustion of fuels were included. The various types of energy use in the main operations of the company are shown in *Table 27.*

Table 27 *Direct energy use of main company operations in the year 2000*

Type of energy use	**Amount of energy used (MWh)**	**%**
Electricity for metro lines	70 940	35.3
Electricity for tram lines	19 074	9.5
Electricity for buildings	40 840	20.3
Electricity for trains	5 576	2.8
Fuel oil for buildings	5 036	2.5
Fuel for buses	53 278	26.5
Fuel for boats	3 000	1.5
Additional vehicles (service etc.)	3 307	1.6
Total	**201 051**	**100.0**

The largest energy-consuming operation is the metro lines, which used close to 71 GWh of electricity, which is 35% of the total energy use of the company in 2000. The fuel for the buses also constitute a large part (27%) of the company's total energy use, while the energy for the buildings is the third largest (20%) form of energy use in the company.

Due to the large energy use in the operation of the main services provided by the company, a series of actions to reduce the energy use has been identified (*Box 1*).

Box 1 *Actions in energy use of main company operations*

Actions in energy use of main operations.

- Plan for reducing energy use in buildings includes prioritising energy-saving actions
- More energy-efficient trams and metro rail cars will replace old ones
- New buses will comply with the EURO IV-norm
- Car-sharing will be applied in the use of the additional vehicles

The main sources of direct CO_2, NO_x, PM_{10} and $PM_{2.5}$ -emissions from the company's main operations are shown in *Table 28.*

***Table 28** Direct CO_2, NO_x, PM_{10} and $PM_{2.5}$ - emissions from the company's main operations*

Source of emissions	CO_2 (tonnes)	%	NO_x (kilogram)	%	PM_{10} (kilogram)	%	$PM_{2.5}$ (kilogram)	%
Buses	14 272	83.1	141 415	85.6	11 570	90.7	8 999	91.3
Buildings (fuel oil)	1 230	7.2	1 172	0.7	64	0.5	45	0.5
Boats	800	4.7	17 600	10.7	466	3.7	363	3.7
Additional vehicles	880	5.1	5 010	3.0	651	5.1	451	4.6
Total	**17 182**	**100**	**165 197**	**100**	**12 751**	**100**	**9 858**	**100**

The combustion of fuel in the buses is the largest source of all three emission components. In total for the year 2000 the use of diesel to run the buses caused emission of 14 272 tonnes of CO_2, 141 tonnes of NO_x and almost 12 tonnes of PM_{10}, of which close to 9 tonnes are $PM_{2.5}$. Direct emissions from rail transport is not included, as this mainly is connected to diesel-trains, which are not used on a regular basis on the rail lines in Oslo.

In reducing the emissions from the main operations the company has implemented several actions and measures (*Box 2*).

***Box 2** Actions for reducing polluting emissions from main company operations*

Actions in emission reduction.

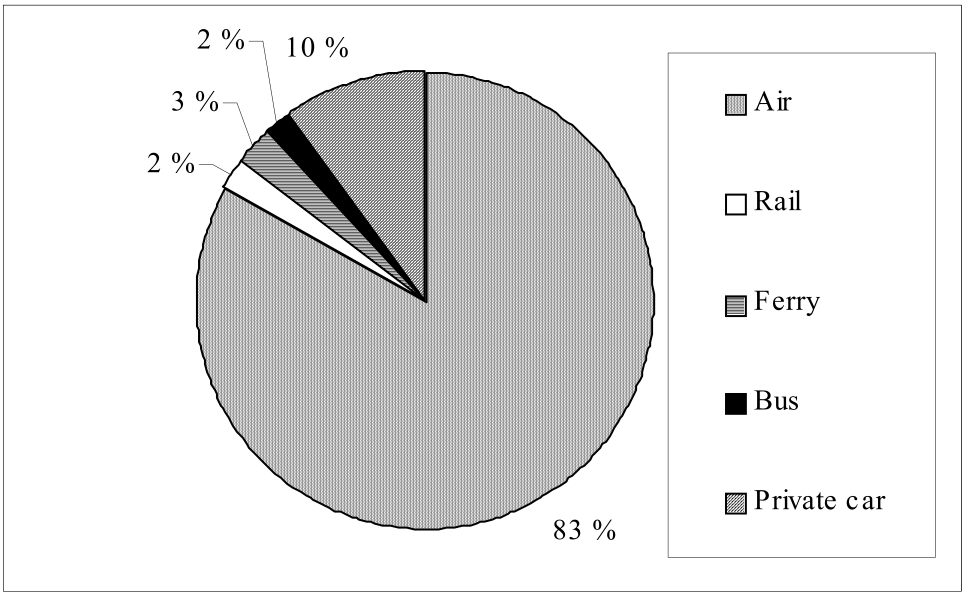
- Modern emission-reducing technology, such as CRT-filters and DeNOx catalysts will be installed on buses
- A transition to the use of low-sulphur diesel is in process for the buses. This is essential for the functioning of the DeNOx catalysts.
- The company supports work on alternative fuels in transport

6.5. Business travel

The transport in the form of business journeys made by the employees of Oslo Sporveier to conferences, meetings, seminars etc. was analysed in detail. The sources of data material for this analysis were two internal reporting systems used by the employees to claim reimbursement for this type of travel activity. The first consisted of forms used to claim reimbursement for travel by public transport or rental car, while the second consisted of forms used to report private car usage on the business journeys. All the forms in these two categories in the company, processed in the year 2000, were used in this analysis. This consisted of a total of 334 journeys by air, rail, train bus or ferry to destinations outside Oslo and Akershus.

The results of the analysis of the company journeys indicated that in the year 2000 they accounted for a total energy use of 535 MWh, the emissions of 356 tonnes of CO_2, 713 kg NO_x and 40 kg PM_{10}.

Figure 35 *Distance travelled by the employees of Oslo Sporveier in business travels, by various transport means in 2000 (Percent)*



In *Figure 35* the distribution of the distance travelled with the various transport forms used on the business journeys is shown. Of the accumulated distance of 810 000 kilometres, air travel constituted 83%, private car 10%, and train, bus and ferry each 2-3%. Air travel accounted for 338 tonnes or 97% of the total CO_2 –emissions from the company journeys. This corresponds to as much as two percent of the total CO_2 –emissions from the company operations shown in *Table 28*. It is therefore important for the company to reduce the air travel. Private car also accounts for a much larger part of the emissions than rail and bus. These are superior justifications for implemented company actions (*Box 3*) aiming at reducing all unnecessary air travel and private car use.

Box 3 *Actions connected to company business travels*

Actions in business travels.

- Restrictions on travel to conferences and meetings outside Norway with only participants from Norway
- Environmental criteria will be used in the approval of business travels
- Conferences and meetings organised by AS Oslo Sporveier will only take place at locations accessible with public transport.

Restrictions on unnecessary business travel and travel by air and private cars are proposed and implemented in various ways through the environmental action plan in the company. Indicators have also been established for measuring the changes in this form of employee travel. They are shown in *Box 4*.

Box 4 *Indicators for measuring the changes in the employee's business travels from year to year*

Indicators for business travels.

- Percent of business travels by bus and train
- Number of business travels by air
- Number of kilometres business travel by car per man-years
- Number of video-/telephone-/Internet-conferences per business travel

6.6. Travels to work

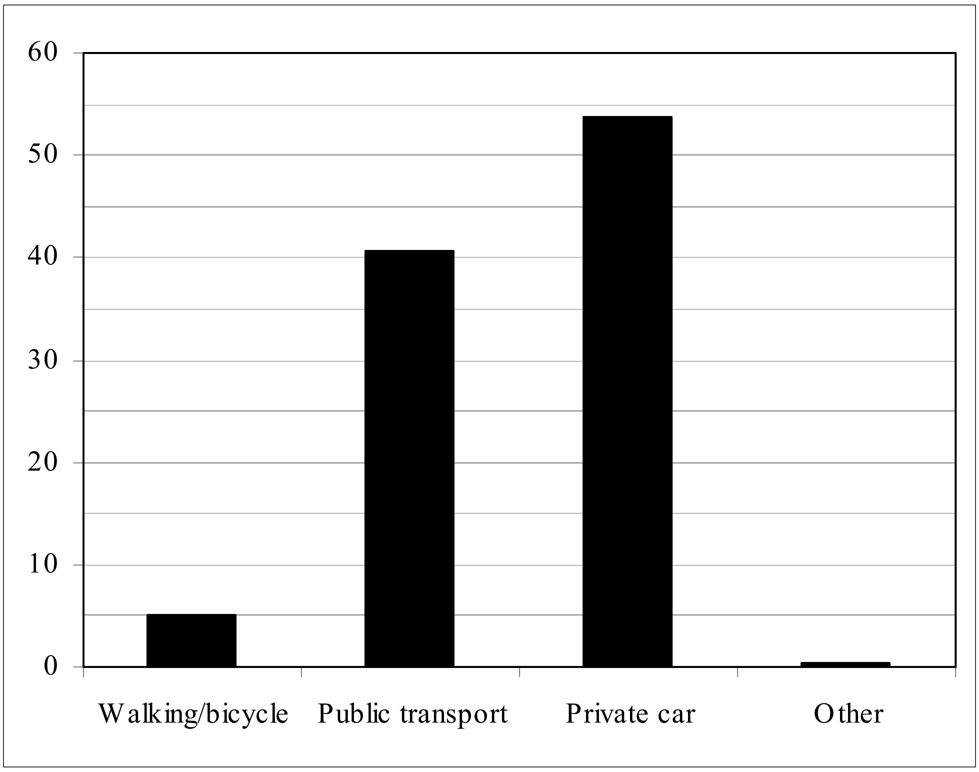
Due to the fact that the daily travels of the company's employees between home and the work place are not common to include in corporate environmental reports, but are particularly relevant for a company providing environmentally friendly transport, it is devoted relatively large space to this type of transport in this article. The work travels performed by the employees of Oslo Sporveier were analysed through a relatively extensive study where 796 of the employees were interviewed on nine of the largest work locations in the company. The total number of employees at the time of the study was 2323. By taking into consideration the amount of part-time employment, answers were obtained from 38% of the total number of man-years in the company, which is the respondent rate in the study.

The interviews were carried out by employees of the company in collaboration with the researches from Western Norway Research Institute. A combination of e-mail and personal interviews was used. Employees with access to personal computer answered a questionnaire distributed by e-mail, while the others were interviewed in-person. Answers were obtained regarding the travel to work on the actual day the questionnaires were sent out and the interviews carried out. The "today's travel" approach used was chosen to reduce the potential source of errors from the employees having to remember their travel far back in time. The disadvantage with this approach is however that the chosen day of the interviews could be an atypical day for various reasons. No such reasons was however identified, except for the fact that the day chosen in November is in a season when the use of bicycling/walking is relatively low. The question of how the bicycling/walking on the day of the interview deviated from the annual average was not answered with this methodological approach. Questions were asked about transport mode, distance travelled, and for the use of private cars, also the number of people in the car during the journey.

The results of the study indicated that the work travel by the employees accounted for an energy use of 11.9 GWh corresponding to 6% of the company's total energy use in year 2000. This is a relatively high number, as the company is a major consumer of energy through the trams, metro and bus services. Emissions of CO_2 from the work travel amounted to as much as 2 963 tonnes, corresponding to 17% of the company's total CO_2 –emissions. The NO_x –emissions amounted to 8.1 tonnes, or 5% of the company total. Approx. 1.6 tonnes of PM_{10}, corresponding to 13% of the total from the company operations were emitted. The reason why the percentage is so much higher for CO_2, NO_x and PM_{10} than for energy is that there is a much higher fraction of energy use in the form of fossil fuels in the work travel than in the total company energy use. A major part of the total company energy use is in the form of electricity for the trams and metro systems.

The result of the study also showed that 428 of the 796 of the work journeys (54% of total) were carried out by private car, while in 324 of the journeys (41% of total) public transport were used for the major (longest) segment of the work journey (*Figure 36*).

Figure 36 *Distribution of Oslo Sporveier employee travels to work on various transport means (percent of total)*



Two additional studies of work travel in Oslo and Akershus County have found private car shares ranging from 58% to 53% (Andersen, 2001). The share of private car use of 54% found in the study of employee work travel in Oslo Sporveier thus indicates a similar private car share as work travel in general in Oslo city and Akershus County. However, as relatively large parts of the company are centrally located in Oslo and with good access to public transport it is reason to expect that the share of private car usage was lower. This share of private car use should however be considered in light of the employees' home relative to the work place location. In *Table 29* the location of the employees' homes in three areas is shown: 1) Oslo, 2) Akershus County and 3) Outside Oslo and Akershus County. Close to 69% of the employees live within Oslo city's borders, with relatively good access to public transport. This supports the expectation of a lower share of private cars than the findings in the study indicate.

Table 29 *The location of the homes of employees in three areas (number and percent)*

	Oslo		**Akershus**		**Outside Oslo and Akershus**		**Total**	
	Number	%	Number	%	Number	%	Number	%
Total Oslo Sporveier	1 631	68.7	585	24.6	158	6.7	2 374	100.0

Analyses of data from an earlier study of travel behaviour for Oslo/Akershus (1990/91) showed the share of private car use relative to the work location at increasing distance from Oslo centre (Andersen, 2001). The results are shown in *Table 30* and *Figure 37*.

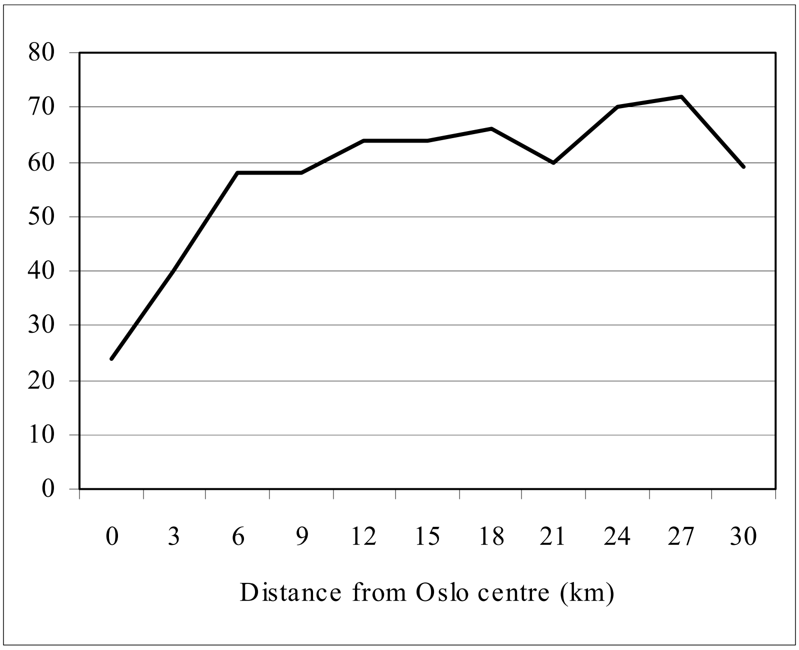
Table 30 *Private car use in work travels, relative to the work location at increasing distance from Oslo centre. 1990/91 (percent of all work journeys)*

Work location	**Private car use in work travels (%)**
Oslo centre	28
Inner city	40
Outer city	55
Akershus County	66
Average Oslo/Akershus	50

Source: Andersen (2001), based on Fosli and Lian (1999)

As seen in *Table 30* the share of private car is relatively low when the work location is Oslo centre. At locations further away there is a substantial but still gradual increase up to the outermost zone: Akershus. In the inner city the share of private car is still substantially below the average of approx. 50%, while it is barely above in the outer city. It is not until a location in Akershus that the share of private car is substantially higher than the average and higher than what referred to above in the other studies of Oslo/Akershus (average 53-58%).

***Figure** 37 Private car usage in travels to work as a function of the distance from the work location to Oslo centre. 1990/91 (Percent of all work journeys)*



Source: Andersen (2001), based on Fosli and Lian (1999)

In *Figure 37* a strong increase in the share of private car out to about 6 km from the Oslo centre is evident. The use of private car is there somewhat higher than the average for Oslo/Akershus. When the work location is gradually farther away from the city the increase in private car share is more moderate. When the distance from the centre is about 25 km the private car share is above 70%.

The study of work travel among the employees in Oslo Sporveier found that at the company locations with the lowest private car use the share of private car is about as would be expected relative to the average for Oslo/Akershus. The basis for the relatively high share of private car for the company as a whole is primarily the high shares (77-86%) of private car usage at three units. The shares of private car usage at these three units are above what one would expect from their location with relatively good accessibility with public transport and situated at node-points in the public transport route network. This is an additional indication that there would be reason to believe that lower shares of private car is possible, facilitated by actions working in that direction at all company units.

The average occupancy rate of the private car journeys in the study of employee work travel in Oslo Sporveier was found to be 1.18 persons per car. This is the same as the occupancy rate on weekdays in Oslo in the morning rush found in a separate study (Andersen, 2001). An average private car occupancy rate of 1.1 for work travel has previously been found in Oslo/Akershus. The Norwegian national average occupancy rate for work travel in 1998 was also about 1.1 (ibid.). The occupancy rate for work travel in Oslo Sporveier is thus somewhat higher than the average both nationally and for Oslo and Akershus. The possible difference is however small. The occupancy rate found in the study of work travels in Oslo

Sporveier is not high enough to rule out the possibilities that company actions could have an effect on increasing the occupancy rate.

Oslo Sporveier has established several actions connected to the employee's work travel (*Box 5*). The first group of actions is aiming at stimulating the employees to use public transport instead of private car. First of all, the employees can travel free on the transport means operated by Oslo Sporveier within the Oslo city border. In addition, the company is operating a system of employee transport, consisting of buses picking up and delivering employees. The superior justification for this system is to make it easier to get to and from work for employees with work hours extending into the night, when the public transport services are not operating. The company has also made an objective to establish a new overall parking policy. A superior goal is to increase the restrictions on accessibility of parking space. These restrictions apply to employees who are not dependent on private car use to and from work.

Box 5 *Actions in Oslo Sporveier connected to the employee's work travel*

Actions in employee work travel.

Actions aiming at stimulating to use of public transport:

- Free travel on public transport operated by Oslo Sporveier
- Employee transport system between work and home consisting of buses picking up and delivering employees
- Parking restrictions for automobiles

Actions aiming at stimulating to bicycling/walking:

- Information on positive health effects of increased bicycling/walking
- Physical facilitating actions for increased bicycle use

In spite of the system with free travel on public transport within the borders of Oslo, and the system of special buses picking up and delivering employees at their homes, the study of the work travel among the employees found a relatively high private car use. On the other hand, the use of public transport – about 40 percent – is substantially higher than the average for Oslo/Akershus. The use of metro is more than twice as high. Seen this way, it is apparent that the stimulating actions, such as the system of free travel, have an effect. The problem however is that they do not appear to result in a lower private car use, but first of all a lower walking/bicycle use. The average in Oslo/Akershus for walking/bicycle use is 18-20 percent, while it was found to be as low as 5 percent in Oslo Sporveier[74].

The second group of actions connected to the employee's work travel consists of actions aiming at stimulating to increased bicycling/walking. As a part of its environmental action plan the company is working towards increasing the

[74] See previous comment in the main text regarding potential error in bicycling/walking rate.

bicycling use by implementing information and facilitating actions for making the use of bicycle a more preferred transport choice. These actions are anchored in the company's HSE work. In addition, an objective of carrying out annually surveys of employee's work travel is established, for the purpose of monitoring the use of various transport modes.

The company has established a set of indicators for the measuring of changes in the employee's work travel from year to year. The indicators are shown in *Box 6*.

Box 6 *Indicators for measuring the changes in the employee's travels to work from year to year*

Indicators for employee travels

- Average percentage of the travels to work performed by private car
- Average percentage of the travels to work performed by bicycle in May or September
- Average occupancy rate for private car travels to work

6.7. Purchasing

The company Oslo Sporveier has selected purchasing as one of the main areas of focus in its environmental action plan. As was briefly touched in the introduction, the energy consumption in the company is high. With energy as such a central issue for the company, it is justifiable to draw attention to the energy use. For the purchasing of energy two aspects of the energy systems are of particular importance for the company:

1. The company Oslo Sporveier consumes large amounts of energy in its operations. For the trams and metro systems electricity is the carrier of energy, while in the bus system fossil diesel is used as energy carrier.

2. The energy systems are understood in an extended societal context. This implies that the energy systems are not limited to the direct energy use for the propulsion of the transport forms. An energy-chain perspective is applied, which means that the source of the energy also is focused upon. This is usually a standard approach in environmental reporting, but it is of particular relevance for a company that consumes large amounts of energy in its operations. In this case, the energy type and quality are important choices for environmental reasons. Information about the amount of purchased energy coming from fossil sources of energy is for example required in determining the company's emissions of climate gases.

Clear possibilities for environmental improvements connected to the purchasing of electricity exist. In the year 2000 Oslo Sporveier purchased almost 70 GWh of electricity for the metros, 19 GWh for the trams, and almost 41 GWh for the buildings. Through the preparation of the environmental report for the year 2000 a discussion was started if the company should start to apply environmental criteria to the purchasing of electricity. For the years 2001/2002, the company action plan specifies that the possibilities for purchasing of environmentally labelled electricity will be investigated, both for the propulsion energy and energy for the buildings. There are many different criteria for environmentally labelling of electricity. Criteria for green electricity according to the Swedish "Bra miljøval" ("Good environmental choice") label guarantee that only the energy sources hydropower, bio energy and wind energy are utilised. The main issue here is to exclude the electricity from coal fired or nuclear power stations. The exclusion of fossil fuel- or nuclear generated electricity implies that the electricity comes from renewable energy sources only, and as such can be considered CO_2 neutral. A decision to switch to only using green electricity can thereby contribute to a reduction in the CO_2 emissions from the company activities[75].

Also for the purchasing of new equipment the company will start to apply environmental criteria. For the upgrading and purchasing of new electrified transport equipment (trams and metro) are increased energy-efficiency and reduction in noise important factors taken into consideration. For the purchasing of new buses is in addition company criteria established for the reduction in exhaust emissions.

Environmental criteria are also established for the choice of suppliers. These include criteria regarding the supplier's environmental policy, environmental report and environmental management system. Indicators expressing the percentage of purchases where the supplies fulfil the criteria are also established. Also for the choice of products, indicators expressing the environmental aspects are starting to be applied. Both life-cycle costs and environmental issues such as eco-labelling, content of recycled material and content of hazardous chemicals are included in the indicators.

6.8. The societal accounting

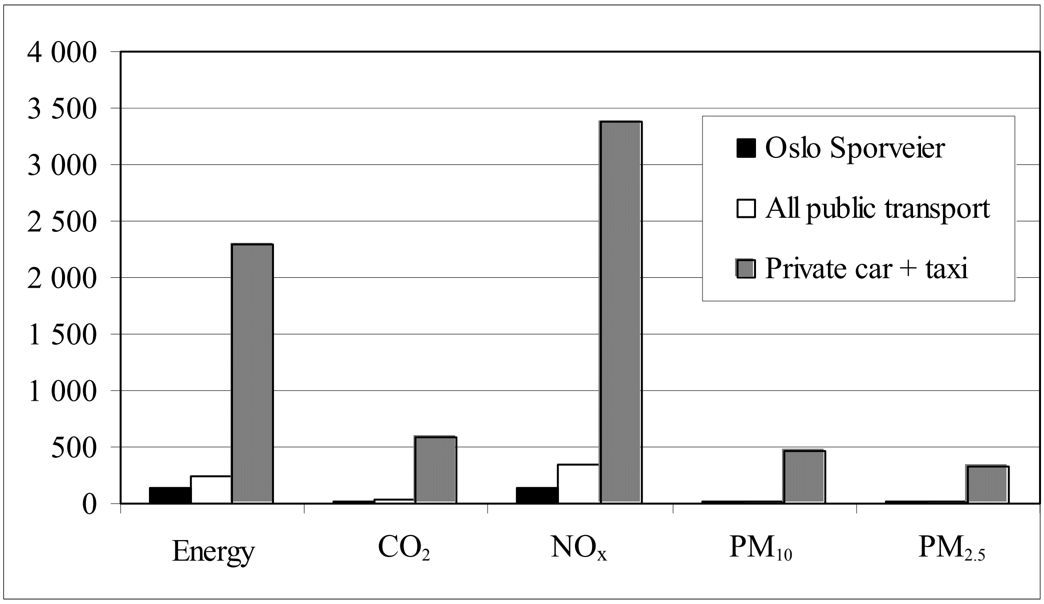
As a way of showing its responsibility as an important societal actor, the company Oslo Sporveier has chosen to disclose its societal account. Through the societal account, the company is demonstrating how the environmental consequences of the company's transport activities compare with other parts of Oslo's person transport system. The company thus uses the societal accounting to communicate important environmental issues to the stakeholders.

The environmental indicators used in the societal accounting for Oslo Sporveier include direct energy use, emissions of CO_2, NO_x, PM_{10} and $PM_{2.5}$. Data for the indicators in the year 2000 was obtained for the company's activities. In addition, data was obtained from the other public transport companies operating in Oslo, to determine the environmental consequences of the total public transport in Oslo. The data for the private cars and taxis in Oslo were obtained by using official

[75] Since basically all electricity produced in Norway is from hydroelectric power, the CO_2 -reduction is based on the assumption that there is a net import of electricity to Norway. This was the case in the years 1997 (3.4% import), 1998 (3.1% import), 1999 (2.9% import), and 2001 (3.0% import). In the year 2000 the situation was however quite different with a net export of 13,3% (Statistics Norway, 2002).

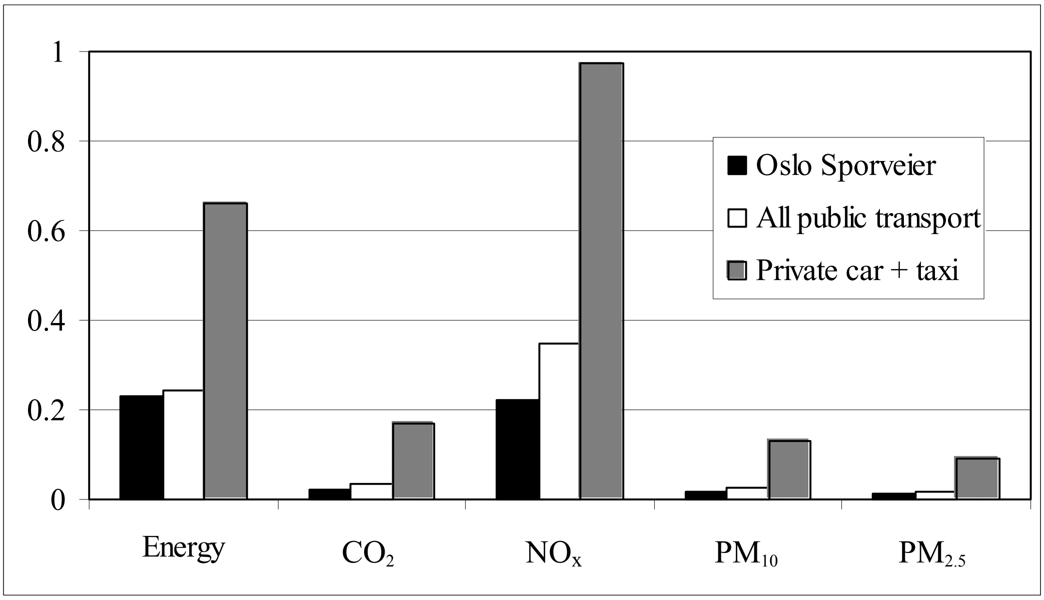
statistics of this transport work and applying average factors for energy use and emissions connected to this transport in Oslo. The results of these calculations are shown in *Figure 38*. From the figure it is evident that the environmental consequences in terms of emissions and energy use for both the public transport as a whole, and for the company's transport activities, are small compared with private car and taxi.

Figure 38 *Energy use and emissions from Oslo's total person transport (Energy in GWh, CO_2 in kilo-tonnes, other emissions in tonnes)*



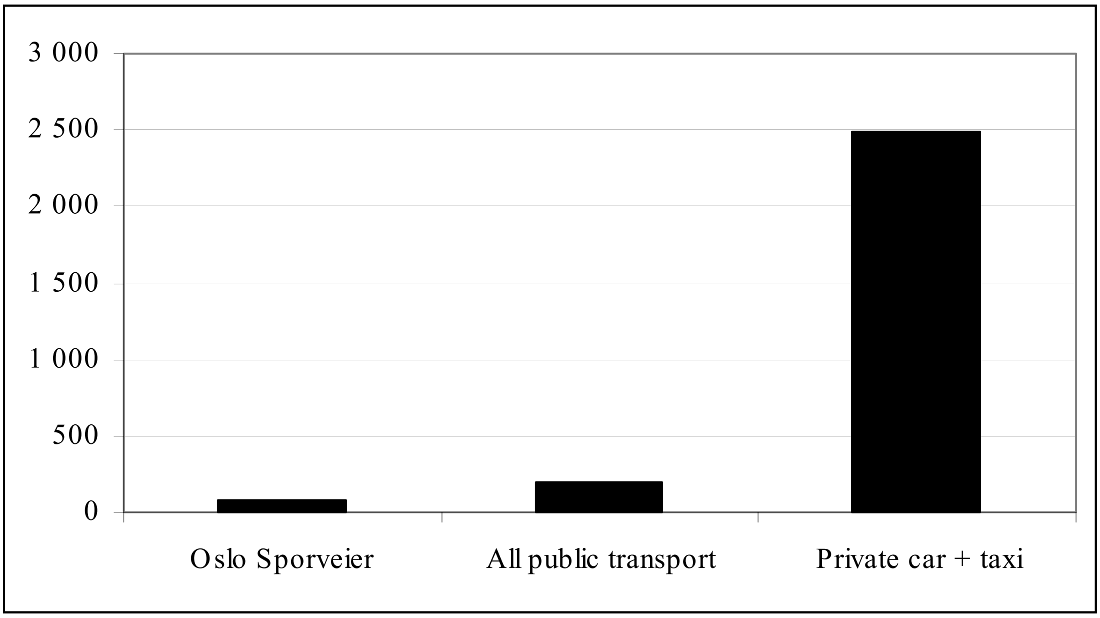
Also the average specific energy use and emissions per person-km for the company's activities, the total public transport and private car and taxi were determined. The comparison in *Figure 39* clearly shows that the average specific emissions and energy use for both the company and the public transport as a whole are much less then for private car and taxi. This indicates that there would be large environmental improvements connected to an expansion of Oslo's public transport.

Figure 39 *Specific energy use and emission per person-km for Oslo's person transport (Energy in kWh/pkm, CO_2 in kg/pkm, other emissions in g/pkm)*



The societal accounting also includes determining the environmental costs of the company's transport activities, the public transport as a whole and the use of private cars and taxis. The results of the calculations of the environmental costs are shown in *Figure 40*. It is evident that the environmental costs[76] of the public transport as a whole and for the company's transport activities are small compared with private car and taxi.

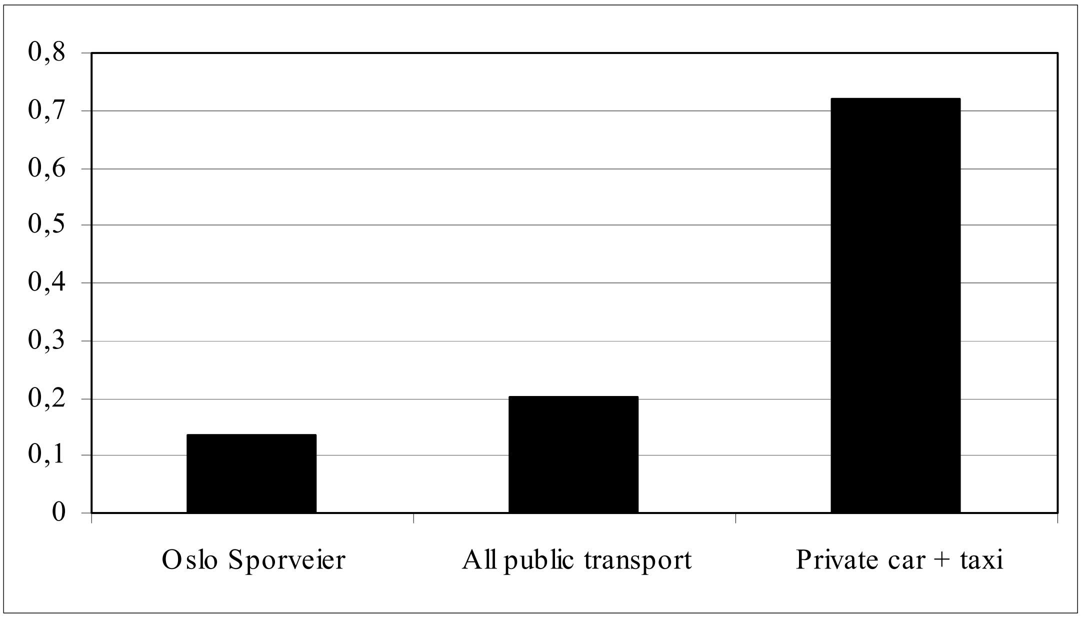
Figure 40 *Total environmental costs of Oslo's person transport (million NOK)*



[76] The calculations of environmental costs are based on a unit cost of 0.35 NOK per kg CO_2, 400 NOK per kg NO_x and 2 050 NOK per kg PM_{10}. The unit cost of $PM_{2.5}$ is included in the unit cost of PM_{10}.

The average specific environmental costs per person-km for the company's services, the total public transport and the private car and taxi were also determined. The comparison in *Figure 41* clearly shows that also the specific environmental costs per person-km for the company's transport activities and public transport as a whole are much less than for car and taxi.

Figure 41 *Average environmental costs of person transport in Oslo per person-km (NOK)*



6.9. Final discussion

In this article environmental reporting in the field of transport is discussed. An example is given of a company strategy that includes, in addition to environmental reporting, also societal accounting.

There are strategically good reasons for a transport company to include the environmental consequences of business travels and travel to work in the environmental report. By disclosing these types of information the company is improving its transparency. This is important for a good stakeholder dialogue. These types of transport activities can cause major environmental impacts, adding to the impacts of the main operations of the company. This is shown for the case of Oslo Sporveier, where the company's total CO_2-emissions increase by 20% and the PM_{10}-emissions by 13% when the employee's company travel and daily travel to work are included.

It is not strategically wise for a public transport company to accept that a large number of its employees use private car to work. This problem is amplified if the occupancy rate of the car use is low. If this is the case the company will easily be subjected to stakeholder critique. The reporting of developments in employee's travels to work is thus strategically advantageous for a company providing environmentally friendly transport.

The case of Oslo Sporveier also shows how an environmental strategy for a company can include specific requirements to the purchasing of energy and materials. It is a logical environmental strategy for a company that purchases large amounts of energy, to apply specific environmental criteria to the type of energy being purchased. Failure to consider the environmental life-cycle, for example of the electricity being purchased, can result in omission of major impacts of the company's activities.

In this article an example is given of how societal accounting can be used in connection with environmental reporting. Through the societal accounting a company can show the environmental consequences of the company's services in relation to other ways of providing the service. Applied to transport services, the societal accounting for Oslo Sporveier is an example of how the environmental consequences of the company's products (services) compare with the total public transport and the private car usage. The results of the societal accounting for Oslo Sporveier clearly indicates that there would be large environmental improvements connected to an increased share of public transport usage, as is also a key element of the company strategy. The societal accounting thus gives important knowledge at the political level regarding the development of a city. In that way it serves the function of supplementing and correcting the scenarios.

It is possible to picture the flow of knowledge through the company strategy and the political level with a "loop". The scenarios provide important knowledge to the political level regarding transport development. The societal accounting corrects and supplements the scenarios. With the help of the societal accounting, the environmental report is thus "lifted" up annually to a political level. This is of high value for a company with important societal functions. The "looping" of knowledge back to the scenarios contributes to change the framework conditions for the company, expressed through the environmental report. A connection between political strategies and the company strategy is thus established.

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7. Alternative Energy in Transport Companies. Industrial Ecology Perspectives on Resource- and Implementation-limits of Biological Fuels

7.1. Abstract

This paper addresses the relations between industrial ecology and alternative transport energy. Limits and barriers to the use of biodiesel from rapeseed and alcohols from wood are discussed by applying industrial ecology perspectives. The paper presents results from the two European Commission DG-XVII ALTENER projects “Biodiesel in heavy duty vehicles in Norway – Strategic plan and vehicle fleet experiments” and “Motor-alcohols from wood resources in heavy duty vehicles. A Nordic project on market-penetration through stakeholder group networks”. These projects gained new empirical material connected to barriers in two main areas: 1) Implementation of biological fuels in transport and 2) Analysis of resource requirements for a larger implementation of biological fuels as energy for transport (mobile energy). The implementation part comprised of fleet tests with biodiesel in two Norwegian bus companies. The main organisational barriers connected to the bus companies, as well as environmental barriers to biodiesel use were analysed. Organisational barriers to biodiesel were identified at different levels (management, garage staff and drivers) in the two companies. The analysis of environmental barriers focused on additives and emissions. The barriers to implementation of motor-alcohols from wood were identified through the forming of stakeholder group networks. These networks of actors from Norway, Sweden and Finland, comprised of members drawn from transport companies, transport organisations, wood-processing industries and manufacturers of wood-based alcohols, distributors of motor-fuels, manufacturers of heavy duty vehicles dedicated for motor-alcohols, and others. The analyses of resource requirements for a larger implementation of biodiesel revealed consequences in various agricultural scenarios. The environmental impacts in terms of land-use, fertiliser use, pesticides and herbicides and the application of transgenic plants were also discussed. The effect of biodiesel on emission of greenhouse gases were analysed in detail using a life cycle approach.

The paper discusses these empirical results from industrial ecology perspectives. An important perspective is the integration of industrial activity with natural ecosystems. A general characteristic of the transport sector is that this industry is a large converter of mobile energy. The mobile energy conversion is the key to the connection to industrial ecology for this type of industry. A case analysis of the two bus companies reveals this connection further. Both bus companies are large converters of mobile energy. The bus companies are responsible for natural resource consumption mainly in the form of fossil fuel combustion. The transition to renewable sources of energy is mandatory for obtaining an improved integration of industrial activity into natural ecosystems. This is an essential element of industrial ecology. The connecting of transport activities up to basic biological systems however raises new questions regarding *volume* as barrier to energy use and alternative fuel implementation. The alternative transport fuels and their associated volume-problems, in terms of limits on emissions and agricultural

production, are likely to be some of the most important topics for industrial ecology in the future.

7.2. Introduction

The transport sector is a major converter of energy. The large energy use is a characteristic of the type of industrial activity represented by the transport sector. Energy is a key factor for understanding the relations between industrial ecology and transport. Energy for transport (mobile energy) can be considered as the main connection between transport companies and industrial ecology. Bus companies are of particular interest, since they are responsible for major natural resource consumption in the form of fossil diesel combustion.

The integration of industry into nature's ecosystems is an important perspective of industrial ecology. Improved integration is a main strategy for reducing industry's negative impact on ecosystems. For the transport sector, the key to this integration is energy. Fossil energy is a non-renewable resource, which is incompatible with cyclic natural resource flows. The transition from exploiting non-renewable resources, towards higher dependence on renewable sources of energy can improve the integration of industrial activity with natural ecosystems. Energy from biological sources is one example of renewable energy. The transition to biologically based energy can thus be a strategy for connecting the transport industry to biological systems, and thus improving the integration with natural ecosystems.

However, problems emerge with the increased transition to alternative mobile energies. First of all, the systems efficiency is low for many of the alternatives[1]. High efficiency is required for future energy systems.

Many of the problems connected to the implementation of alternative fuels are not solvable by purely technical measures, but are present in the form of *volume* problems. An example of a volume problem is the large amounts raw materials required for the production of alternative fuels for the rapidly increasing number of private cars. This is a different form of problem than, for example, the problem of reducing the exhaust emissions of automobiles. The latter is an example of an *efficiency problem*, consisting of *making things better*. Volume problems are however connected to the necessity of making *reductions.*

The resource requirements for larger implementations of bio-based fuels can exceed available land. Larger implementation of biodiesel produced from rape (rape methyl ester, RME) for example, can be severely restricted by the agricultural land available for this production. The environmental impacts of this production can in addition consist of increased leaching from fertiliser use, damages from pesticide usage, and the application of genetically modified crops. Another area of concern is the effect of biodiesel usage on the emission of greenhouse gases. This is not well enough understood from a life cycle perspective of the fuels.

Industrial ecology is about making changes to society. Changes are implemented through the involvement of *actors* and through *structures*. Barriers to implementation of alternative energy can be connected with both actors and structures at various societal levels. At the level of individual transport companies, implementation barriers can be present at different organisational levels (management, garage staff and drivers). Environmental barriers can also be present and connected to additive usage and emissions, of concern during transport, storage and final combustion of alternative fuels.

The engaging of actors is important for implementation of alternative energies. The formation of stakeholder group networks with a wide range of actors represented is one way of identifying, and possibly resolve barriers. The actors included in a stakeholder group network for biologically based motor- alcohols would for example include transport companies, transport organisations, wood-processing industries and manufacturers of biologically based alcohols, distributors of motor-fuels, and manufacturers of heavy duty vehicles dedicated for motor-alcohols.

7.3. Research basis

The empirical data material presented here is based on two European Commission DG-XVII ALTENER projects:

1) "Biodiesel in heavy duty vehicles in Norway. Strategic plan and vehicle fleet experiments"

2) "Motor-alcohols from wood resources in heavy duty vehicles. A Nordic project on market-penetration through stakeholder group networks"

The main objective of the former project was to develop a strategic plan for deployment of biodiesel in heavy-duty vehicles, applicable both for Norwegian Federation of Transport Companies and bus companies. Fleet tests with biodiesel in buses were carried out to provide empirical foundations for the plan. Particular focus was on barriers when driving in cold weather, and barriers in the production chain of RME.

The latter of the two projects aimed at identifying, in collaboration with Ecotraffic R&D in Sweden and VTT in Finland, barriers in the production, distribution and usage of wood-based motor-alcohols. This was done through the forming of stakeholder group networks for wood-based motor-alcohols.

7.4. Company barriers to biodiesel use

To generate more knowledge of the barriers, fleet tests[2] with biodiesel were conducted in the project. Through the tests, barriers were identified in connection with driving and starting in cold weather. Both technical, environmental and health aspects of fuel- and additive-usage were included. Barriers related to the three company levels administration, driver and workshop were identified through interviews in connection to the fleet tests.

At the *management* level of the organisation the main barrier was the price of biodiesel. Unless the price is at least 10-20% below the price of fossil fuel, to compensate for the higher fuel consumption, the bus companies are not likely to use biodiesel. Another important barrier at the management level is the vehicle manufacturers' reluctance to give full approvals for biodiesel use. Bus companies are therefore not using biodiesel from the fear of potential engine damages.

At the *driver* level the most important barrier is the reduced engine-power of biodiesel. Fear of not being able to drive according to the route's time schedule is thus a barrier to the implementation of biodiesel.

Among the staff in the *workshop* the most important barriers were connected to the fear of more maintenance work in the form of more frequent changes of lubricating oil and filters. There was also a noteworthy uncertainty among the workshop staff regarding the health effects of additives used in biodiesel.

7.5. Biodiesel use in cold ambient temperatures

The barriers connected to driving and starting in cold ambient temperatures were also identified. These barriers encompassed the following:

1) Biodiesel does not work as well as mineral diesel in cold winter temperatures. Special precautions must be taken when operating in cold weather.

2) The use of additives in biodiesel represents potential environmental and health-related problems[3]. Several of the most common winter-additives in use today are carcinogenic and exhibit potential pollution threats in the case of spillage and accidents.

A literature study[4] of biodiesel additives indicated that problems with driving in cold weather are overcome by using additives. Environmental and health problems are however connected with additives used to obtain improved winter properties ("cold flow additives") and other additives.

Additive products marketed are almost always mixtures of different compounds blended together into additive packages to provide several functions simultaneously. Substantial research is conducted in improving fuel properties by finding combinations of different types of additives (Wilson, 1997). This implies that the environmental effects of additive usage are not limited to the effects of individual compounds. The possibility for synergistic effects of each individual compound must also be taken into account when assessing the effect of additives on health and environment[5].

7.6. Biodiesel production barriers

The most important barriers connected to Norwegian production of biodiesel based on the energy-crops rape and colza were identified. The total agricultural land in Norway in 1998 was 1.04 million hectare (2.57 million acre). One third of this, 0.33 million hectares, was used for cultivation of grains, mainly barley, oats and wheat. Oil seed was cultivated on approx. 7 600 hectares. This is less than 1% of the agricultural land[6]. In 1991, oil seed cultivation reached a maximum of 11

400 hectare (Statistics Norway, 1998). Barriers were identified in three different scenarios for future agricultural systems in Norway. The three systems are:

1) An organic agricultural system
2) A traditional agricultural system
3) A high-technological intensive agricultural system

The assumptions connected to each agricultural system are shown in *Table 31*. These assumptions are optimistic, especially regarding the available land, the yield, and the improvements in yield and oil seed content from the application of genetic engineering.

Table 31 *The assumptions made in the three different agriculture systems for year 2005*

	System		
	Organic	**Traditional**	**Intensive**
Available land (ha)	250 000	300 000	300 000
Oil seed cultivation frequency (year)	6	5	3
Annual land use (ha)	42 000	60 000	100 000
Average yield (tonnes/ha)	1.5	2.5	2.5
Oil content in seeds (%)	45	45	55

It is only possible to reach the replacement percentages in these systems with an active application of policies to further develop systems for increased biodiesel use. It is only within the scenario of a high-technological intensive agricultural system that it is possible for biodiesel to replace a significant portion (>15%) of the fossil diesel consumption in heavy-duty vehicles[7] (*Table 32*). Major environmental barriers are however connected to this scenario. Problems from the application of genetic engineering, excessive use of chemicals and artificial fertilisers are some examples[8].

Table 32 *The biodiesel replacement potential of three different agriculture systems in year 2005 (tonnes and percent)*

	Tonnes	**%**
Total diesel use in heavy duty vehicles	900 000	100.0
Intensive agriculture	156 240	17.4
Traditional agriculture	76 680	8.5
Organic agriculture	32 220	3.6

7.7. Effects of biodiesel on emissions of greenhouse gases

Emissions of nitrous oxide (N_2O) from rapeseed cultivation have a large effect on the total CO_2 -balance in RME production and usage. New estimates of N_2O emissions from rapeseed cultivation indicate that this effect is larger than previously assumed by Figenbaum (1995) [9]. The effect on the CO_2 -balance of using updated estimates on N_2O emissions were analysed, and complimented with more recent data from Statistics Norway (1998) on land use.

The results from the study by Figenbaum (ibid.) indicate a reduction of 1.90 kg fossil CO_2 emissions per kilo RME used (by-products included). These reductions represent 60% of the total CO_2 -emissions from mineral diesel use. Using the data from Figenbaum, with the new estimates on N_2O -emissions, we get the results shown in *Table 33*. These are results based on the intensive and the traditional agricultural scenarios. As shown in the table the lowest estimate in the calculations (-50% error in the calculation of the N_2O -emissions) will reduce the CO_2 –emissions to about the same level as in the Figenbaum study (ibid.). But in the middle estimate the reduction in CO_2 -emissions from a transition to RME use is only 17%. The "highest" estimate (+50% uncertainty in the calculation of the N_2O -emissions) actually gives a 15% *increase* in greenhouse gas emissions with the replacement of fossil diesel by RME.

Table 33 *Effect of biodiesel on the emission of greenhouse gases*

			Uncertainty	
	Figenbaum study (ibid.)	**This study**	*-50%*	*+50 %*
N_2O-emissions (in CO_2- equivalents: kg/hectare)	636	1 655	*828*	*2 482*
Net reduction (kilogram CO_2 / kilogram RME)	1.9	0.55	*1.60*	*-0.50*
Net reduction (%)	60	17	*50*	*+15*

The new estimates of N_2O emissions from rape production indicate that RME's positive effect on reducing greenhouse gas emissions is smaller than previously assumed.

7.8. Barriers to wood-based motor-alcohols

The barriers to implementation of motor-alcohols from biological material were identified through the forming of stakeholder group networks[10]. These networks of actors from Norway, Sweden and Finland, comprised of members drawn from transport companies, transport organisations, wood-processing industries and manufacturers of wood-based alcohols, distributors of motor-fuels, and manufacturers of heavy duty vehicles dedicated for motor-alcohols.

The stakeholder group network agreed upon that bio-based motor-alcohols should be considered primarily a long-term strategy for the reduction of CO_2. Both methanol and ethanol are important future fuels for vehicles. Both the blending of alcohol in petrol/diesel and use of pure methanol/ethanol are relevant strategies. Alcohols can be used as fuel in both light and heavy-duty vehicles.

Among the key problems for increased use of motor-alcohols is the high production cost for bioalcohols considered the main barrier. The absence of long-term government policies for biofuels in the Nordic countries is also an obstacle for the further development of motor-fuel systems based on bioalcohols. A long-term perspective is not present today, but will have to be necessary for future implementation.

One main strategy identified for resolving the barriers is to establish *co-operative channels* to major governing bodies. Such channels are important in promoting the use of bio-alcohols by businesses and organisations in their negotiations and dialogues with the governmental authorities.

7.9. Conclusions

The implementation of alternative energy is important for integrating industrial activity into the ecosystems of nature, an important industrial ecology principle. The transition from fossil energy to renewable energy use is thus a form of industrial ecology strategy applicable to transport companies. The alternative energy forms are however not compatible with industrial ecology unless they have high life-cycle system efficiency.

Main problems connected to industrial ecology are however emerging with the increased utilisation of alternative mobile energies. Many of the important problems, such as the agricultural land requirements and the large amounts of nitrous oxide emissions from rapeseed production, are problems emerging from the large *volumes* to be replaced by alternative fuels. The barriers connected to volume problems are less easily resolved than the problems of developing new or adapting existing motor technologies to alternative fuels (efficiency problems) [11]. Both biodiesel and wood-based alcohol can in general be used with existing motor technologies. Barriers are however present in transport companies, as is shown in two bus companies.

For a large implementation of biodiesel produced from rapeseed in Norway, a main barrier is the limited agricultural land available for this production. Even with the application of a high-technological intensive agricultural system it is not possible for biodiesel to replace more than about 17% of the fossil diesel consumed by heavy-duty vehicles. Even with this low replacement major problems would be likely to emerge, in the form of excessive application of genetic engineering, chemicals for pesticide control and artificial fertilisers.

Biodiesel is commonly promoted as being CO_2 –neutral, based on the thought that the amounts of CO_2 emitted to the atmosphere during the combustion is compensated by the CO_2 – assimilation by the plants. The assumption of CO_2 –neutrality is however not necessarily valid when the production of biodiesel is analysed in more detail. Particularly the nitrous oxide emissions during the cultivation have large effects on the total balance of greenhouse gas emissions in RME production and usage. Our study indicates that biodiesel's positive effect on the reduction in the emission of greenhouse gases is smaller than previously assumed.

From the experiences with the stakeholder group network on wood-based motor-alcohols, it is noteworthy that all the stakeholders in the stakeholder group network agreed upon working towards further implementation of wood-based motor alcohols. Even the oil companies, which have their basis in the production and distribution of fossil fuels, agreed in supporting the implementation of alternative energy in the form of wood-based motor-alcohols.

7.10. Notes

[1] With *system efficiency* we understand the life-cycle efficiency of the energy alternatives. This includes the energy efficiency during the production, distribution, reforming, and final use (conversion) in the vehicles. For many alternative fuels the energy system efficiency is lower than for fossil fuels. Bio-methanol used in fuel cells can however compete with fossil diesel in terms of total system efficiency (Ahlvik & Brandberg, 2001). In exergy-based considerations, the biological alternatives usually come out better in terms of system efficiency. This is due to the fact that the biological fuels are based on renewable raw materials and the bi-products to a large extent are returned back to nature's *renewable flows*. Connected to this, it is common to differentiate between *dead stocks* or *deposits* and *living stocks* or *funds.* Deposits and funds are defined with regard to the difference in the time of reproduction. Natural flows and flows from funds are often called *renewable flows.* It is also possible to distinguish between deposits and funds by means of origin. Deposits, such as fossil energy sources, origins from matter that is being removed from the recycling processes in the biosphere, and placed into the lithosphere. Funds, such as trees and plants, however, are part of the cyclic processes in the biosphere, powered by the sun.

[2] Fleet tests with biodiesel were conducted in two bus fleets. Driving with biodiesel was conducted in the two transport companies Sogn Billag and Firda Billag during March 1997 and January-February 1998. Three buses were driven a total of 25 000 km and consumed approx. 11 000 litre of biodiesel during these tests. The lowest temperature recorded during the test period was –11 °C. No major problems occurred during the test periods. The drivers however reported somewhat reduced engine yield, especially noticeably when driving the bus up steep hills. The fuel consumption increased 10-20 percent compared with fossil diesel driving. A few passengers responded negatively to the characteristic odour of the biodiesel exhaust.

In the project title the term "fleet experiments" is used for the biodiesel driving in the bus companies. However, in describing the methodological approach applied in the project, it is more correct to use the term "fleet tests". The term "experiments" signals the use of controlled conditions and rigid methods, such as in conducting repeatable sequences of laboratory experiments. "Fleet tests" implies less controlled conditions, more like a "case" for obtaining experiences and knowledge. The fleet tests with biodiesel gave empirical experience and knowledge of applying biodiesel as a fuel for buses.

[3] An important strategically question regarding the implementation of alternative energy forms is: Why is this important to elucidate the health and environmental problems connected to the various energy forms? The question can be answered by applying two different perspectives. The first is the structure-perspective: If there is not much environmental benefits to gain from a transition to alternative energy, then the transition is not compatible with industrial ecology. The second

explanation is based in the actor-perspective: The various alternative energy forms have emerged out of an environmental discourse, from the understanding that they are important in achieving environmental improvements. The knowledge of the various aspects of the alternatives is important to generate and disseminate, because a successful transition to alternative energy forms requires that all central actors (stakeholders) support the transition. It is quite problematic if some of the central actors are opposing the energy form in question. In the transition to alternative energy forms, environmental organisations are important actors. It is thus a major problem if an environmental organisation is opposing some aspects of the transition to an alternative energy form. The use of genetically modified organisms (GMO) in connection with development and production of biological fuels is an example of an issue connected with strong opposition. Another example is the use of additives with damaging health and environmental effects. A third example is that large implementation of RME in most countries is only possible with intensive agricultural systems.

In the process of obtaining knowledge of the various aspects of the alternative energy forms and dissemination it to the stakeholders, the focus on barriers is important. Comprehensive knowledge is necessary for successful implementation. The focus on the barriers is based in the understanding that unforeseen effects of alternative energy forms must be avoided. The barrier-focus is thus applied to give the actors knowledge of what is required for overcoming the barriers.

[4] The goal was to obtain an overview of the usage of different types of additives applicable for biodiesel. This knowledge overview is a starting point for evaluating environmental, health and safety aspects of additive usage. This can provide an aid in the identification of barriers to implementation of biodiesel. Some indications of such environmental aspects are included in the final report from the project (Andersen et al., 1998). The results from the study by no means constitute a complete overview of different additives in use. A major problem in this regard is the proprietary information of many additive compositions, only available to the additive producers.

The USA EPA suggests that the possible environmental problems from emissions of biodiesel additives primarily consist of nitrogen oxides and aldehydes (Sopota, 1997).

Most additives in the USA are recommended used in concentrations up to 2 000 PPM (2%), which means that 20 gram of the active ingredient can be added to 1 litre of the fuel. The Austrian standard for biodiesel however has an upper limit of 1% for additives.

There are at least four different reasons for using additives in biodiesel:

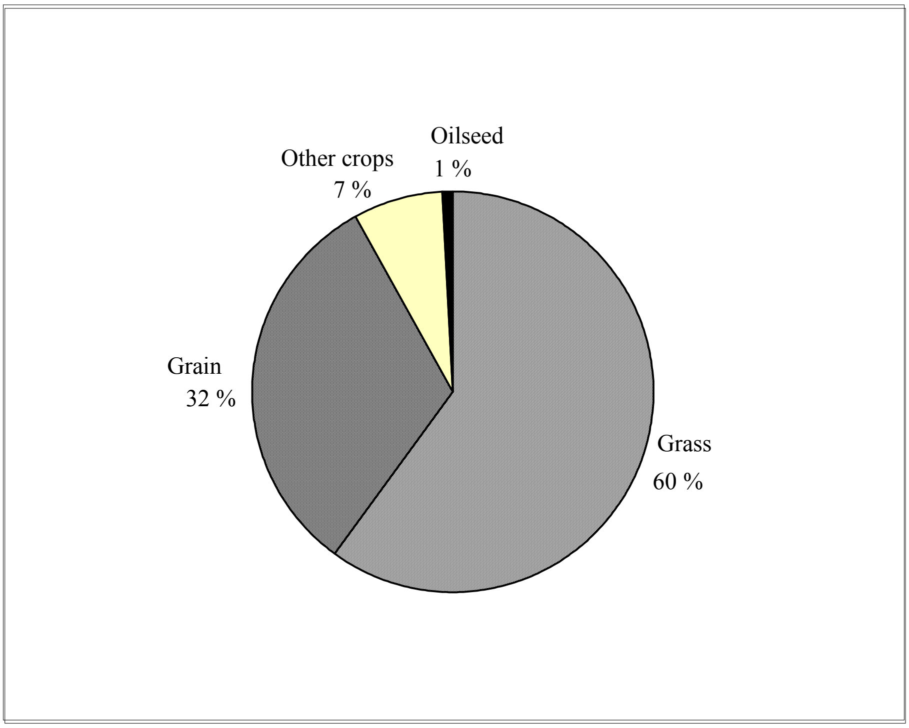
1) At temperatures below -5 ^{o}C it is necessary to improve the flow properties of biodiesel to avoid plugging of fuel lines and filter. Two different terms are being used to describe the cold flow properties. CCFPP is an abbreviation both for *critical cold filling pouring point* and for *critical cold filter plugging point*. With a CCFPP of -20 ^{o}C the fuel is suitable for use at temperatures down to -20 ^{o}C. Additives that

increase the cold flow properties, by lowering the CCFPP, are termed *pour point depressors* (PPD).

2) The use of biodiesel can cause the formation of deposits in the engines, mainly on intake valve shafts and injection systems. Additives used to reduce this deposit-forming tendency are named *dispersant supplements*.
3) RME has a high content of unsaturated fatty acid methyl esters (FAME). The double bonds are vulnerable to oxidation. Contact with metal can also result in oxidation that reduces the stability of the fuel. A wide range of antioxidants and metal-passivators (increasing the metal compatibility) are being used to extend the shelf-life of biodiesel.
4) The different fatty acids that are esterified to form biodiesel possess different ignition properties. The ignition properties are described in terms of *cetane numbers*. Including additives can improve the ignition properties of biodiesel by reducing the time delay between the injection and the ignition. This will increase the cetane number of the fuel.

[5] This consideration must be taken into account both regarding combustion products, emissions and physical contact.

[6] The agricultural land use (% of each crop) in Norway in 1997 is shown in the following figure:



[7] In the resource analysis for biodiesel a Norwegian national perspective is chosen. In principle, much larger amounts of biodiesel could be produced in other countries, where climate and agricultural conditions are more favourable, e.g. in Germany, and imported for use in Norway. However, transporting alternative fuels over long distances, such as currently is being done with fossil fuels, is not a

good solution. The national perspective is based in an environmental discourse, with to a large extent agreement that in order for future energy forms to be environmentally sound, they must be compatible with the three principles of:

1) Self-support
2) Local-regional systems for production, distribution and consumption
3) Nature integration: The integration of industrial activities into nature's ecosystems

The calculated share of fossil diesel use that biodiesel can replace is for the diesel use in heavy duty vehicles only. The share is substantially lower when the fossil diesel use in private cars, taxis, agricultural machinery, boats and ferries are taken into consideration. The total use of fossil diesel in Norway is approx. four times the amount used in heavy duty vehicles, resulting in a total replacement potential of only 4% for the most intensive agricultural scenario.

[8] Some environmental organisations are opposing large-scale biodiesel use from the perspective that it requires a high-intensive agriculture. There is a particular strong opposition to the use of genetic engineering. The development of new plant properties by the use of genetic engineering can represent a conflict with the *precautionary principle*, as there is uncertainty regarding the future environmental consequences of this technology. The precautionary principle states that if there is scientific uncertainty regarding irreversible effects on the environment from an activity, the lack of full scientific proof for the effects is not a good enough argument for continuing with the activity.

[9] N_2O -emission is not only an impact from cultivating rapeseed, but from all agricultural cultivation. The most important factors for N_2O -emissions from agriculture are:

1) Industrial production of fertiliser
2) Use of mineral fertiliser and manure
3) Runoff/leakage from mineral fertiliser and manure
4) Decomposition of plant-material (plant-rests).
5) Nitrogen-fixation by bacteria
6) Livestock on pasture

In the analysis of N_2O form rapeseed production the three first factors are included. The percentage of nitrogen in fertiliser and runoff that ends up as nitrogen in N_2O is shown in the following table:

Source	**Factors**
Production of fertiliser	0.54% N in fertiliser as N in N_2O
Use of fertiliser/slurry	1.25% N in fertiliser as N in N_2O
Runoff/leakage	2.50% N in runoff as N in N_2O

Source: Rypdal (1998) and Jevne (1998)

The N_2O-emissions from rape seed cultivation, using 150 00 tonnes mineral fertiliser in the intensive/traditional agriculture system, and 95 000 tonnes manure in the organic agriculture system are as follows (in kg N_2O / hectare):

	Intensive/Traditional agricultural system	**Organic system**
From production of fertiliser	1.27	0
From fertiliser usage	2.95	1.87
From runoff/leakage	1.12	1.12
Total N_2O-emissions	**5.34**	**2.99**

The intensive and the traditional system will result in emissions of 21.4 gram N_2O per kilogram rapeseed produced. The corresponding figure for the organic system will be 19.9 gram. On a land area basis, the emissions of CO_2 will be 1 655 kilogram per hectare for the intensive and the traditional system, and 925 kilogram per hectare for the organic system.

[10] The formation of stakeholder group networks is based in the actor-perspective of industrial ecology, by which it is understood that changes to society are implemented through the involvement of actors. Successful implementation of alternative energy forms can only be carried out through the involvement of stakeholders (actors). Stakeholder group networks can be placed within the concept of *environmental co-operative regimes*. Such regimes had not previously been applied within the area of expanding the use of alternative energy forms in transport. From a strategic policy point of view, the environmental co-operative regime is an example of *co-operative environmental governance* as described by Glasbergen (1998). Lafferty and Meadowcroft (1996) describe these types of regimes as implying the process of bargaining and cooperation among groups, and between groups and governments – for the successful management of environmental problems. The regimes work to solve environmental problems by clearly defining the responsibilities of each member and then negotiate on concrete agreements on how to achieve a goal. The "groups" participation can come from established producer and consumer organisations, trade and professional associations, scientific and educational institutions, religious and charitable foundations, in addition to environmental organisations and even from corporations whose environmental credentials are under scrutiny. Each group may be concerned with one or more dimensions of the environmental debate, and their activity may range from public education and campaigning to private lobbying of the bureaucracy and elected officialdom. Through such regimes can the significance of environmental degradation more rapidly be brought into the open; a fuller picture of social and ecological interconnections among issues may be built up; and a wider range of policy options can emerge and be subject to critical scrutiny.

Through constructive dialogue, reflection, negotiation and compromise can the participating groups arrive at an agreed solution to the problem in question. Each participant assumes some responsibility for the implementation of the agreed solution and debate allows for further mutual understanding and facilitates redefinition of group interests within the context of a broader common interest. A commitment to search collectively for a solution leads to the development of a joint "action plan" to which each party feels an attachment (ibid.).

The joint action plan from the project's stakeholder group network consisted of actively supporting and promoting the further development and implementation of bio-based motor-alcohols. The strategy identified by the stakeholder group network for resolving the barriers was to establish *co-operative channels* to major governing bodies. Through the project quite new cooperative channels were actually established, in a setting encompassing three different countries. Both on the Nordic level and within each of the three countries were conditions thus established for a further contact and cooperation after the end of the project. In the Norwegian context this was undertaken through the activities of the Norwegian Bioenergy Association.

[11] Even though the understanding of transport problems in industrial ecology often is limited to *efficiency* problems, the *systems approach* of industrial ecology opens up for inclusion of volume problems.

7.11. References

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8. Conclusions

The superior problem issue addressed in this thesis has been:

- How can we understand relations between industrial ecology and transport?

Three leading issues have been derived from the superior problem issue:

- To what extent are transport problems themes in the various understandings of industrial ecology?
- How are transport problems understood in industrial ecology?
- What is the role of actors in the relations between industrial ecology and transport?

The problem issues of the thesis have been addressed by throwing a broad light on the field of transport and industrial ecology. Both theoretical contributions and case analyses of various segments of industrial systems are used to illustrate the relations between industrial ecology and transport. The review of the industrial ecology theory field gives principal insight into the problem issues, while the empirical cases provide illustrative examples of the transport questions that emerge with the use of industrial ecology as a framework.

8.1. The typologies

Three typologies are used for elucidating the problem issues of the thesis. They each represent different perspectives on the main problems. The typologies are:

- The typology of industrial ecology
- The typology of transport problems
- The typology of actor involvement

The typologies are applied both in theoretical discussions, and through the five empirical cases.

8.1.1. The typology of transport problems

The various forms of transport problems in this thesis have been characterized according to the dimensional axis efficiency-pattern-volume (*Figure 42)*. This system of characterising transport problems has basis in on previous research conducted by Western Norway Research Institute (Høyer et al., 1998; Høyer, 2000). The problems on the axis range from relatively simple problems connected to the lack of *efficiency* of existing transport, to successively more complex problems of societal systemic character caused by the high *volume* of transport. In addition to these two main dimensions, the axis has an intermediate position for problems of transport being caused by the relative usage (*pattern*) of different transport forms.

The *efficiency* problems of transport are connected to the aim of making improvements in existing transport. This consists of mainly technical problems connected to improving the environmental performance of existing transport and creating new and more efficient transport means. Examples are problems connected to the design of more energy-efficient automobiles, and cars emitting less polluting substances. Also problems of less technical character, e.g. in the form of driver behaviour and capacity utilisation (passenger occupancy rates, goods load factors) are forms of efficiency problems.

Figure 42 *Typology of transport problems*

Efficiency problems
- Problems with the lack of efficiency of existing transport. How to improve the environmental performance of existing transport and create new and more efficient transport means?

Pattern problems
- Problems caused by the relative usage of different transport forms (modes and means). How to change the pattern of transport, to environmentally preferred alternatives?

Volume problems
- Problems caused by the volume of transport, which is the sum of all the in the individual uses of automobiles, aeroplanes, and lorries etc. How to make reductions in transport volumes?

The transport *pattern* problems can be discussed in terms of how to make changes in the relative usage of different transport forms. This includes the substitution of transport environmentally preferred alternative modes and means. Transport on water and rail instead of road and air are key mode substitutions. Bus instead of automobile is an example of a transport mean change. Mode substitution in transport can imply major savings in energy use.

The *volume* problems are connected to the necessity of making reductions in transport. The problem is therefore how societal and individual processes can reduce motorised transport of both people and goods. This includes questions of how to establish industrial infrastructure and land use practices that minimise the need for motorised transport. How to locate societal functions for improving accessibility is another problem aiming to reduce the need for transport.

Many different types of transport problems have been addressed in the five empirical cases. They illustrate how transport can be addressed with the use of industrial ecology as a framework. The transport problems can also be discussed in the context of the various understandings of industrial ecology. Relations between industrial ecology can then be shown through an analysis of the principal transport problems, and complementing this with the actual problems in the cases. This is obtained through a discussion of potentials and limits for industrial ecology to include various transport problems.

8.1.2. The typology of industrial ecology

The typology of industrial ecology is based on a review of the literature contributions by central authors in the field of industrial ecology. The typology differentiates the main understandings of industrial ecology into five theoretical understandings (types). The types have different characteristics (*Figure 43*) expressed through contrasting conceptual elements.

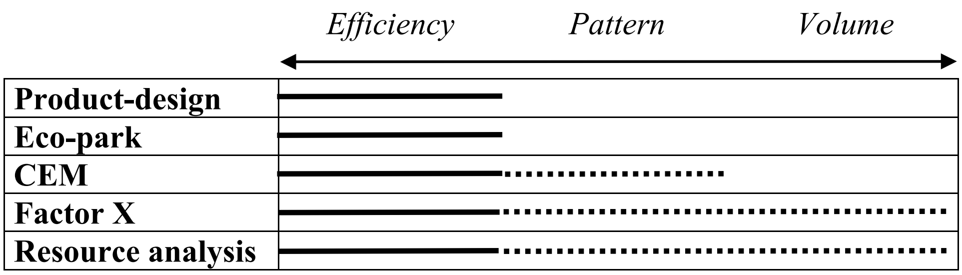
Figure 43 *Industrial ecology types and their main characteristics*

	Limited vs. total	Gradual vs. radical	Nature integration vs. analogy	Material vs. energy	Product vs. production
Product design	limited	gradual	integration	material	product
Eco-park	total	gradual	analogy	material	production
CEM	limited	gradual	integration	both	production
Factor X	total	radical	integration	both	product
Resource analysis	limited	gradual	integration	material	production

As indicated in *Figure 43,* the understandings of industrial ecology as mainly consisting of product design, corporate environmental management and resource analysis all focus on relatively limited changes in existing industrial systems. The eco-park and factor X understandings deal with larger (or total) transformations of industrial activity. In all the understandings except factor X, the focus is on gradual extensions to existing industrial systems rather than radical alterations. In the eco-park understanding the analogy to nature is predominant, while the other understandings focus on improving the integration of industrial systems into nature. In most understandings of industrial ecology there is a higher focus on material considerations than on energy issues. Only in the factor X and CEM understandings have reasonable balance between energy and material considerations. The product-design and the factor X understandings have main focus on products, while the other understandings focus mainly on issues connected to production and production systems.

The types also have different potentials for handling transport questions. In each industrial ecology understanding, the transport problems commonly addressed in the literature contributions form the basis for *Figure 44* (also presented in Chapter 2).

Figure 44 *The potentials of industrial ecology types for handling various forms of transport problems*



As shown in *Figure 44*, the main focus in all main understandings of industrial ecology is on efficiency problems (indicated by solid lines in the figure). This is due to the fact that mainly efficiency problems of transport are dealt with in the literature contributions to industrial ecology. Two of the five understandings can in addition be considered limited to *efficiency* problems. The product-design and the eco-park understandings are mainly suited for dealing with problems connected to the efficiency of transport.

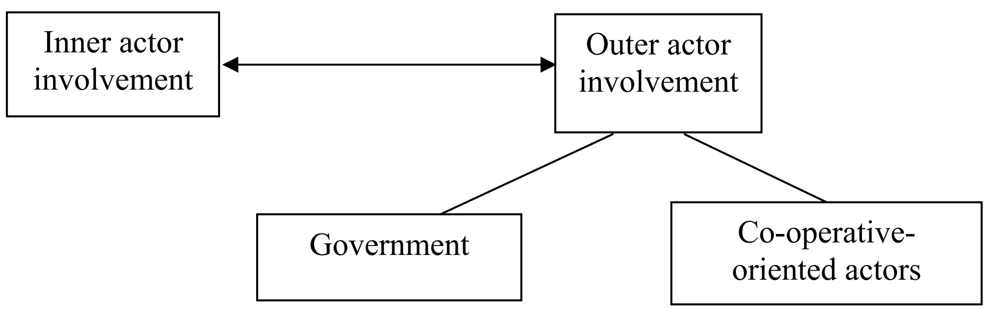
The three other understandings cannot be considered limited to efficiency problems, but also include pattern and/or volume problems (indicated by dotted lines in the figure). In the corporate environmental management understanding, it is also possible to point to examples where *pattern* problems are dealt with. This is however not common. Transport issues in the factor X and the resource analysis understandings in addition include some thematics connected to volume problems, and these understandings have a better potential for handling volume problems of transport.

8.1.3. The typology of actor involvement

The third typology concerns the involvment of different actors. Clarkson (1995) makes a differentiation between primary and secondary corporate stakeholders. A primary stakeholder is "one without whose continuing participation the corporation cannot survive as a going concern", whereas secondary stakeholders are "those who influence or affect, or are influenced or affected by, the corporation, but are not engaged in transactions with the corporation and are not essential for its survival". According to such a classification, primary stakeholders are investors, employees, customers, suppliers, governments and communities. Secondary stakeholders include media and activist groups.

It is also possible to differentiate between *inner* and *outer* actors (*Figure 45*). This typology is more applicable for characterising the role of actors in the empirical cases dealt with in this thesis. With inner actors we understand the actors within an organisation, e.g. in a company. Employees at different company levels are examples of inner actors. Outer actors are actors outside the company organisations. The outer actors can be of two main forms, government as actor and cooperative-oriented actors.

***Figure 45** The actor typology*



The co-operative-oriented actors include suppliers and customers, branch organisations, interest groups and stakeholder groups. The government can however also be represented in the stakeholder groups.

Using the differentiation described above, inner industrial ecology actors identified in the theoretical contributions and the empirical cases include industrial engineers and designers involved in the design and development of new products, with improved environmental performance. The concepts “eco-design” or “design for environment” are central in industrial ecology (Steinhilper, 1995; Lifset & Graedel, 2002; Hendrickson et al., 2002). When designers and engineers are applying these design-concepts on transport systems, including vehicles and infrastructure, efficiency improvements can be made for future transport systems.

In connection with the implementation of alternative fuels are employees of transport companies important inner actors. Due to the advantages of centralised distribution systems for alternative fuels, the transition to alternative transport fuels is likely to first occur in fleets of vehicles. In bus companies, employees at many different levels of their organisation are important for the implementation of alternative fuels. At all the three levels management-, driver-, and garage-level, can barriers be present. Barriers can exist at all these different levels, and the employees are important in identifying and resolving the barriers.

As inner actors must also be included the employees of individual companies seeking to take part in the formation of industrial ecological clusters. In areas with high density of industrial facilities, these actors are important for identifying possibilities for waste exchange, and utilisation of recycled material in the production. However in rural areas, this form of actor involvement is restricted by structural conditions, i.e. long transport distances.

As *outer actors* are governmental actors in the position to influence, form and decide upon national policies and strategies for alternative energy forms. Some of these actors have opinions on positive and negative aspects of various energy sources, and can play roles in, for example, facilitating the transition to renewable energy forms. This can also include lawmaking processes for forcing of environmentally superior technology and practices, such as through taxation laws for internalisation if external costs in products and services (eco-taxation).

Governmental actors are also connected to the mandatory requirement of some environmental management systems, as supervisory agencies for the regulations, such as the Norwegian internal control system. In addition must certifying bodies for standardised environmental management systems, for example Det Norske Veritas (DNV) for ISO 14001 and EMAS, be considered as also important outer actors.

Public sector and consumer organisations are among the most important outer actors of the cooperative oriented type. By demanding “greener” (e.g. eco-labelled) products and services these outer actors can contribute to a change in the direction of improved integration of industrial activities into the ecosystems of nature.

Branch organisations play a function as outer actor by deciding upon standards and codes of conduct pertaining to industrial producers. Responsible Care programs and Product Stewardship codes developed by the Chemical Manufacturers Association in the USA are some examples of these actor involvements. The Responsible Care program have been adopted by the sister organisations in other countries, for example through the Federation of Norwegian Process Industries (PIL) in Norway.

8.2. Conclusions on industrial ecology typology and the cases

Here I make some conclusions on relations between industrial ecology and transport, using the typology as a basis for analysing how transport can be understood in the cases. Most of the industrial ecology understandings have characteristics connecting them to one or several of the empirical cases. The cases can thus be considered to represent the application of various understandings of industrial ecology. *Table 34* shows which industrial ecology understandings are applied in each empirical case. Some of the understandings are represented by more than one case. For these understandings, the case that represents a minor application is indicated by a parenthesis enclosing the case name.

Table 34 *Industrial ecology understandings applied through each empirical case*

Industrial ecology type	**Case**
Product design	(Case 5 - Alternative mobile energy)
Eco-park	Case 1 - Rural SMEs
Corporate Environmental Management (CEM)	Case 3 - Transport scenarios in a company strategy Case 4 - Environmental reporting in a public transport company (Case 5 - Alternative mobile energy)
Factor X	None
Resource analysis	Case 2 - Transport of fish from Norway Case 5 - Alternative mobile energy

The characteristics of the industrial ecology understandings that connect them to one or several of the empirical cases, together with the transport problems expected from theoretical analysis in chapter 2, are described in the following:

The *product design* understanding of industrial ecology is characterised by a focus on the design of products. In case 5 - Alternative mobile energy – biofuels can be considered a product. Even though it in many ways can be considered a natural product, and not an industrial product, there are many aspects connected to this product that can have industrial characteristics. The processes of cultivation of the biological raw material and processing into final energy products are some examples.

In the literature contributions to the product design understanding of industrial ecology, transport problems are mainly considered as forms of efficiency problems. It is thus to be expected that mainly efficiency problems of transport are dealt with in this understanding, as represented through the case of alternative mobile energy.

In the *eco-park* understanding of industrial ecology the main focus is on recycling networks and waste trading between industrial facilities. This is the main focus in case 1 - Rural SMEs. The eco-park understanding of industrial ecology is thus represented mainly by an application of this empirical case.

In the literature contributions to the eco-park understanding transport has a minor focus. Those few transport considerations found are mainly limited to questions of *efficiency*. It was thus to be expected that mainly efficiency problems of transport emerge with the application of the eco-park understanding of industrial ecology.

The *corporate environmental management* (CEM) understanding of industrial ecology is characterised by a main focus on environmental management in corporations. Corporate environmental management, in the form of development of environmental strategies, is the main focus in case 3 - Transport scenarios in a company strategy. Environmental reporting is also closely connected to environmental management in corporations, and this is the main focus in case 4 - Environmental reporting in a public transport company. The CEM understanding of industrial ecology is thus represented by the applications of these two empirical cases. In addition, in case 5 - Alternative mobile energy – the development of corporate strategies for alternative energy are addressed. This can also be considered an example of environmental management in transport companies. The CEM understanding of industrial ecology is thus also represented by this case.

The literature contributions to the CEM understanding of industrial ecology indicate that transport is not well included in this understanding. When transport considerations are found it is mainly in the form of questions of efficiency. Some considerations of transport patterns are also present, but these usually have a minor focus. It was thus expected that transport, for a large part could be addressed with efficiency problems of transport, and perhaps some pattern problems in the application of the CEM understanding of industrial ecology. This is not a static situation, as there might be indications that pattern and volume problems are becoming more important for this understanding. With the application of concepts connected to the wider implications of corporate activities, such as Corporate Social Responsibility (CSR), there might be that transport questions requiring more comprehensive approaches are beginning to emerge.

In the *resource analysis* type of industrial ecology the main focus is on understanding the flow of resources in the industrial systems. Case 2 - Transport of fish from Norway – is mainly an analysis of energy use in the natural resource system based on fish. The resource analysis understanding can thus be considered to represent an application through this case. In case 5 - Alternative mobile energy – the main focus is on analysing barriers and limitations for the increased utilisation of renewable energy resources. This can also be considered an application of the resource understanding of industrial ecology.

Transport has a weak focus in the resource analysis understanding of industrial ecology, based on literature contributions within this type. The few transport considerations that can be found in the resource analysis understanding have themes with main focus on efficiency problems. The resource analysis understanding however includes some themes connected to volume problems and pattern problems, but only with minor focus. It was thus to be expected that efficiency problems of transport would dominate with the case-application of the resource analysis understanding of industrial ecology.

In summary, most of the various understandings of industrial ecology derived from literature are represented through the four empirical cases. Four of the five types of industrial ecology understandings have characteristics that connect them to one or several of the cases. Relations between industrial ecology and transport are elucidated through the application of these understandings through the empirical cases.

From the various understandings of industrial ecology derived from literature contributions (the typology) it was to be expected that mainly transport problems of the efficiency category were addressed. Questions of pattern and volume are addressed to a lower extent in the literature contributions.

8.3. Conclusions on transport problems and industrial ecology

This part describes what transport problems have been analysed in the cases. The transport problems from the cases are examples that illustrate how the environmental problems connected to transport within the frames of industrial ecology can be addressed. It is also shown how the transport problems in the cases are complementing the handling of transport problems in the industrial ecology understandings derived from the literature contributions.

8.3.1. Conclusions on the transport problems in Case 1: Rural SMEs

Case 1 is about rural industries and how they are affected by the application of industrial ecology principles. The rural location of the industries implies long transport distances to nearby industrial facilities. If the enterprises are striving for participation in industrial recycling networks, potentially more transport might be generated. Only in those instances where industrial clusters already exist are there possibilities for limited amount of transport connected to the rural industrial ecosystems. The problem of *transport-generation in recycling systems* is about transport volumes, and the problem that more transport can be generated through the establishing of industrial ecosystems in rural areas.

If rural industrial activity is to be included in industrial ecosystems, a wide range of conditions must exist. These include systems for re-generation of waste, which must be located close to the participating industrial facilities, to reduce the transport. This problem is less in branches where the industrial facilities can re-use some of the waste material that is produced. This is the situation in large parts of the wood-processing industry, for example, where waste wood material is utilised as an energy source in heating the facilities. The existence of a separate recycling facility is not a precondition, if the industrial facilities can take back end-of-life products, and integrate the recycle/reuse activities within the facility's activities. "Scavengers" – industry that can utilize waste as raw material, must in general also be present nearby in larger recycling networks. Better utilisation of return trips, to reduce the extent of empty driving, can however reduce the transport in connection with recycling systems in rural areas. If a large number of return trips can be used for taking back used products and waste for recycling, the condition of nearby ”scavenger” industries becomes less important.

If the industrial ecology principle of increased recycling (loop-closing) is applied to rural SMEs, and the conditions described above not exist, increased transport might be a result. The problem of increased transport in connection with recycling networks is not commonly included in industrial ecology. The case of rural SMEs is however an example that illustrates the importance of also considering the potential for transport-generation in connection with recycling systems.

Another transport problem dealt with in Case 1 is the *increased global transport of goods*, both of raw material and finished product. Some of the rural SMEs are components of production chains experiencing a strong degree of globalisation. The production chain in this case is aquaculture fish. One SME is a part of the chain in the form of a producer of fish feed, another as a producer of packaging material for the transport of fish. Long global transports of the raw material for the fish feed and of the finished fish product to the costumers are the essentials of this transport problem. The increase in global transport is in sharp contrast to the necessity for transport reductions to attain a society based on sustainable production and consumption.

When limiting transport to efficiency problems, it is possible that the environmental impacts from transport in the total product chain are not being addressed. A danger exists in industrial ecology, of missing the problems connected to the increase in global transport of goods. The energy use for goods transport, both of raw materials and final products, has increased rapidly the last decades. Fish produced by aquaculture, and distributed globally, is a product chain that experience a strong global increase in energy use for transport. More comprehensive questions of the increase in global transport volumes in many product chains could be asked within the frame of industrial ecology.

To Case 1 is also connected the problem of applying new telecommunication technologies as means for reducing the need for transport. One of the enterprises in the case was implementing advanced telecommunication technologies solutions in the form of remote virtual reality -based employee training and servicing. This was in part motivated by the potential for environmental improvements in the form of reduced need for travel. *Telecommunication’s effect on transport* can in this context be considered *volume*-related. This is due to the fact that it is the reduction (or sometimes increase, due to urban sprawl and travel stimulation) in transport activity that is affected. The effect of telecommunication can also constitute a pattern effect. The availability of telecommunication technologies such as internet-connected portable computers makes it possible to be far away from the work place, and still perform the job. This particularly applies to long journeys, having a potential for facilitating more air travel. However, tele-/video conferences have the potential for the opposite development, reducing unnecessary air travel.

Treating transport mainly an efficiency problem is a limitation for understanding the potentials in information and telecommunications technology (ICT) for reducing the needs for travelling. The potentials of ICT to substitute transport have been discussed for decades. It is quite clear that ICT has potentials for improving transport logistics and substituting travel by e-commerce and telecommuting, for example. The actual effects of applying *telecommunication, as a mean for reducing transport,* is however more uncertain. This can best determined by studying *actual* changes in transport *volumes*. The rather low focus on the volume problems of transport in most understandings of industrial ecology is a limit for addressing this issue well.

Case 1 is representing an application of the eco-park understanding of industrial ecology. The transport problems addressed in this case are all mainly *volume* problems, but two of them, transport-generation in recycling systems and telecommunication's effect on transport, can also be considered pattern problems. The literature contributions illustrate that transport mainly is treated in the form of problems of efficiency in the eco-park understanding. The application of the eco-park understanding of industrial ecology raises in addition important pattern and volume questions connected to transport. This is shown through the case. It is thus possible to conclude that in addition to efficiency problems, also pattern and volume problems of transport can be addressed in connection with the eco-park understanding of industrial ecology.

8.3.2. Conclusions on the transport problems in Case 2: Transport of fish from Norway

The *increased global transport of goods* is also a problem in Case 2. Through this case it is shown that the growth in energy use connected to aquaculture has been particularly large in the transport activities of this product chain. For two components of the product chain, catch of raw material (fish feed) and the distribution of the final product to the customers, this increase has been particularly strong. The increase in mobile energy use from the globalisation of the production chains clearly constitutes a volume problem, first of all in the form of amounts of energy used and amounts of greenhouse gas emissions connected to the combustion of fossil fuels. The major part of the mobile energy used in the aquaculture production chain is in the form of fossil fuels. The increase in the number of transcontinental air transports of fresh whole fish is of particular concern, due to the emissions of high volumes of greenhouse gases. Greenhouse gases are more detrimental when emitted at high altitudes. The greenhouse effect of the CO_2 emitted by the world's subsonic fleet in 1992 for example, has been estimated to be a factor of 2.7 larger than if the emissions would have occurred at sea level (IPCC, 1999).

The increasing volumes of energy used for global transport in the industrial system connected to aquaculture fish has implications both for the product form and for the transport mode used in the transport of the finished product. The implication for the product form of the final product is first of all a necessary transition from whole unprocessed fish to processed (dried, smoked) fish to reduce the high energy use in the transcontinental transports. The change in product form facilitates changes in transport pattern. For this case the change in transport pattern consists of a mode change *from air transport to the more energy efficient sea transport*. The necessity for this mode change is not obvious when the main focus is on efficiency themes. Case 2 illustrates the importance of addressing the necessity for this mode change.

The third main transport issue in Case 2 is also connected to pattern. It is the *mode change from road-based transport to more rail and sea transport* between Norway and the European continent. The lowering of energy use and emission of greenhouse gases are the primary reasons for this substitution, but also the volume-effect in the form of congestion on the European road networks is a motivating factor for making these changes in the transport pattern. Particularly the increase in lorries through the Alpine region has been problematic in the recent years, causing Germany, Italy, Switzerland and Austria to develop and impede measures for restricting this transport, such as through the "ecopoint" lorry permit system[77]. More of this transport is currently being transferred to rail through the region.

Case 2 represents mainly the application of the resource analysis understanding of industrial ecology. Two of the main transport problems dealt with in the case, the mode change air to sea and road to rail are clearly *change* oriented. Based on the process of identifying the various types in the typology (Chapter 2.2) it was not expected that these two problems were connected with the resource analysis understanding of industrial ecology. This is because the resource analysis understanding of industrial ecology has a main focus on *analysing* resources and their flow through society. The analysis however generates knowledge, which can form a basis for obtaining *changes* and improving the industrial metabolism. Change can thus be considered more an indirect result of applying this understanding of industrial ecology.

8.3.3. Conclusions on the transport problems in Case 3: Transport scenarios in a company strategy

The case is about the environmental consequences of different developments in person transport in Oslo up to year 2016, discussed in light of the company strategy of Oslo Sporveier. *Energy use for transport* is determined in three different scenarios. Energy use in transport is a problem that can be connected to all three dimensions efficiency, pattern and volume. Change to energy efficient vehicles can reduce energy use. It is then an efficiency effect. Relative changes between the usages of different modes of transport can have consequences for the energy use. It has then a pattern effect. The increase in total energy use for transport creates environmental problems due to demand for increased production volumes of energy. It is then a volume effect.

Emissions of greenhouse gases are also determined for person transport in three different scenarios. This is usually considered a volume problem, due to the climate effects of large volumes of greenhouse gas emissions. However, both

[77]The "ecopoint" lorry permit system is intended to restrict the number of heavy goods vehicles in transit through the Alpine region. The number of "ecopoints" paid is proportional to the quantity of pollution emitted by the lorry. The total number of ecopoints at the disposal of each country is fixed annually, and reduced each year (EU, 2000a).

efficiency and pattern approaches can have impacts on this problem. More efficient engines, consuming less fossil fuel can reduce the CO_2 emissions, while relative changes between the usages of different modes of transport also have impacts for the CO_2 emissions.

Also *emissions of* NO_x are determined for person transport in the three different scenarios. Emission of NO_x from the exhaust of vehicles is usually considered an efficiency problem. To reduce this problem catalytic converters are used. However, relative changes in the usages of different modes of transport can also have consequences for the emissions of NO_x. The total emissions of NO_x from transport can constitute a volume problem, due to the health and environmental effects of large volumes of this pollutant.

The use of catalytic converters is an example of how volume problems can emerge when transport is limited to efficiency problems. Catalytic converters can actually increase the energy use and the emission of greenhouse gases. The converters require energy to carry out the catalytic reaction of pollutants into less harmful products. This can give higher fossil fuel consumption, and consequently higher emissions of CO_2. Another example is that increased use of catalysts in automotive applications increases the demand for *Platinum*-group metals. These metals are only found in scarce deposits in nature, and the mining involves encroachment into large areas of land, movement of large volumes of earth and leaves behind polluted tailings and ground water.

In the transport scenarios the *emissions of particles* is also determined. The generation of the two particle fractions $PM_{2.5}$ and PM_{10} are determined for the main forms of person transport connected to the three different scenarios. Also the emission of particles is commonly considered an efficiency problem, in connection with controlling these emissions from the exhaust of vehicles. The installation of particle filters is one example where emission of particles is treated as an efficiency problem. The transition to other forms of transport with less particle emissions, such as away from private cars to public transport in general, will however have the overall effect of reducing particle emissions. Particle emissions are also connected to the volume of transport, as the high volumes of road –based transport cause substantial particle-generation from wear of tires, road surfaces and brake pads/linings. The use of particle traps is also an example of how volume problems can emerge when transport is limited to efficiency problems. The traps require high operating temperature and energy input during regeneration processes, contributing to high fossil fuel consumption and correspondingly high CO_2 –emissions.

Case 3 represents an application of the CEM understanding of industrial ecology. From the theoretical contributions it is expected that first of all *efficiency* problems, and secondly *pattern* problems of transport are addressed this CEM understanding. The case illustrates clearly that also volumes problems of transport can emerge, in addition to efficiency and pattern problems in this understanding of industrial ecology. It must however be emphasised that the case company is a transport company, with a high overall transport focus.

8.3.4. Conclusions on the transport problems in Case 4: Environmental reporting in public transport

In Case 4 the environmental reporting from the public transport company Oslo Sporveier is analysed. The company aims at improvements in the activities by looking into how it can switch to using more *renewable energy for transport*. Choosing suppliers delivering environmentally labelled electricity for the transport services is one way the company is addressing this problem. In addition to mainly constitute an efficiency problem, the transition to using more *renewable energy* in transport can also be considered a volume problem. In the literature contributions to industrial ecology energy has a low overall focus. This is contributing to a general weak handling of renewable energy in industrial ecology. The case illustrates that discussions of renewable energy forms can however have a place in industrial ecology. An inclusion of renewable energy discussions would improve the ability of industrial ecology to deal with future sustainable energy systems for transport.

Another efficiency transport problem discussed in the case is how to improve of the *occupancy rate of the private cars* used by the company employees in the travel between home and work. The problem of how to increase the occupancy rate of cars is an efficiency problem. Through the case it is shown that the company is addressing this problem by developing indicators for increased utilisation of the capacity in the cars used by company employees. If successful, such actions could contribute to an increase in the average overall occupancy rate of cars. The overall occupancy rate of cars in Norway has, as previously dealt with in Chapter 2.10.2, been reduced from 1.86 to 1.77 persons per car in the period 1987-2000 (Rideng, 2001).

Case 4 also includes *pattern* transport problems. The substitutions of transport modes/means are dealt with in several ways. In the area of business travel by the employees, pattern changes are aimed at through the implementation of actions to favour *the use of public transport instead of private car* to conferences and meetings. One example is that conferences, seminars and meetings organised by the company only will take place at locations accessible with public transport. Also in the travels by the company employees between home and work, the company is aiming at obtaining pattern changes from private car use to public transport. The company is implementing actions in two main areas to obtain this. Primarily it is achieved by the system of free travel by public transport for the company employees. Secondly, by the employee transport system between work and home consisting of buses picking up and delivering employees. Parking restrictions for automobiles at the work locations are also implemented to favour the use of public transport.

The parking restrictions on private cars can also have the effect of *increasing the use of bicycling/walking*. This effect can in addition be obtained by the information on positive health effects of increased bicycling/walking, and the physical facilitating actions for increased bicycle use that the company is implementing. Some cities, for example Amsterdam and Copenhagen, have achieved relatively high shares of bicycle use, through bike- and walk-friendly policies and city planning.

There are also transport *volume* problems connected to Case 3. The company has been looking into how to *reduce business travels* by the employees. Actions and measures have been implemented for restricting travel to conferences outside Norway with only participants from Norway, for example. The company is in addition supporting more use of *video-/telephone-/Internet-conferences* with the goal of reducing employee business travel.

Case 4 represents an application of the CEM understanding. The transport problems present in this case cover all three dimensions efficiency, pattern and volume. From the literature contributions it has been shown that that first of all efficiency problems, and secondly pattern problems of transport are addressed in the CEM understanding. The analysis in Case 4 thus illustrates that also volume problems, in addition to pattern and efficiency problems are relevant in this understanding of industrial ecology. As was also relevant for Case 3 it must be emphasised that the case company is a transport company, with a high overall transport focus.

8.3.5. Conclusions on transport problems in Case 5: Alternative mobile energy

In Case 5 the implementation of *renewable energy for transport* is discussed. Barriers connected to the use of two forms of alternative transport energy, biodiesel from rapeseed, and alcohols from wood-based raw material are studied. The transition to use of alternative renewable energy is commonly considered an *efficiency* problem. The renewable energy forms are in general contributing to improvement of the environmental performance of transport, resulting in more efficient transport systems.

Through Case 5 it is however shown that also many *volume* problems emerge with the increased use of alternative energy forms. The air emissions from the combustion of alternative fuels can cause serious environmental problems, if a high number of vehicles are using renewable fuels in the future. The *emissions of greenhouse gases* are usually reduced with the transition to alternative fuels. However, the reduction is not necessarily dramatically, when a life-cycle approach is applied. This is shown when the nitrous oxide emissions are included in the analysis of the production of rapeseed as raw material for biodiesel. The emission of greenhouse gases can also be addressed by efficiency and pattern approaches. It can be a result of more fuel-efficient vehicles and mode transitions to more energy efficient transport.

The problem of reducing exhaust emissions from transport is commonly considered an *efficiency* problem that can be solved by improved emission control. The installation of catalytic converters and exhaust filters are common ways to deal with this problem. The reduction in the emission of CO_2 is however obtainable only through a reduction in fossil fuel consumption. Historical reductions in fuel consumption due to increased fuel efficiency have however been more than outweighed by an overall increase in motorised road transport. The life-cycle of biological fuels also results in emission of greenhouse gases, although (usually) to a lesser extent than with the combustion of fossil fuels. The emission of greenhouse gases connected to the use of biological fuels thus also constitutes a *volume* problem, if a high number of vehicles will be using these fuels in the future.

The high agricultural *land use requirement* for the production of rapeseed for biodiesel production *is* another form of *volume* problem connected to this alternative transport energy. The analysis of raw material requirements connected to the use of biodiesel from rapeseed indicates that only about 4 percent of Norway's total fossil diesel use for transport can be replaced with biodiesel produced in Norway. This is even an optimistic estimate of the replacement potential, achievable only in a high-intensive agricultural scenario. Such an agricultural system can however cause other kinds of environmental problems, from excessive application of genetic engineering, chemicals for pesticide control and artificial fertilisers. The seriousness of theses damages is however dependent on agricultural and environmental policies.

Another problem connected to the use of biological transport fuels is the use of *fuel additives*. With a large-scale introduction of biological fuels in the future the effects of the additives on health and the environment need to be thoroughly understood. Without knowledge of the long-term health and environmental effects of the additives, detrimental consequences cannot be excluded. This is a problem connected to the use of biological fuels in general, as many different additives are used for enhancing the performance of the fuel in the motors – already today. The problem is however particularly important connected to the use of biodiesel in cold regions of the world. In cold temperatures special winter-additives are used in addition to the general additive mixtures. The fact that the producers of the additives are reluctant to release the compositional information on the products and consider them trade secrets enhances the seriousness of the problem.

The case illustrates that the additive usage can lead to the emerging of *volume* problems. The increasing use of alternative fuels will lead to increasing volumes of additives in use. Detrimental consequences for health and environment might be a result. The large volume of additive usage is also a complex issue. Additives in sale are almost always mixtures of different chemical compounds blended together into additive packages to provide several functions simultaneously. Substantial research is being conducted in improving the fuel properties by using different combinations of various types of additives. This implies that the environmental effects of additive usage are not limited to the effects of individual compounds. Synergistic effects of each individual compound can enhance the complexity of the problems, both connected to the distribution and handling of additives and the fuel/additive mixtures, and the combustion products (emissions).

Case 5 is mainly representing an application of the resource understanding of industrial ecology. However, the case also has properties that imply a connection with both the product design and the CEM understandings. For the same reasons as explained for Case 2, even though some of the main transport problems addressed in the case are connected to change, they can be still be connected with the resource analysis understanding.

From the literature contributions it was shown that first of all *efficiency* problems, and to a lesser extent *pattern* and *volume* problems of transport are addressed in the resource understanding of industrial ecology. The product design is limited to *efficiency* problems, while the CEM understanding in addition to *efficiency* problems also addresses, but to a lesser extent, *pattern* problems. The analysis of Case 5 thus illustrates the importance of also considering volume problems of transport, in the resource analysis understanding, as well as in the product design and the CEM understanding of industrial ecology.

8.3.6. Final conclusions on transport problems in the cases

The five cases illustrate transport problems connected to industrial ecology. The transport problems in the cases cover all three dimensions efficiency, pattern and volume. From the literature contributions to the various understandings of industrial ecology some conclusions on principal relations to transport ca be made. Mainly transport problems of *efficiency*, to a lesser extent *pattern*, and to an even lesser extent *volume*, are addressed in the literature contributions to industrial ecology. The fact that this is not reflected in the cases can be explained by the main emphasis, in the empirical cases, on giving illustrative examples of the volume problems connected to transport. It is however clear that, as an aid in giving a broad picture of the field of transport and industrial ecology, the cases provide additional knowledge by illustrating how the environmental problems connected to transport can be addressed. The cases emphasise the importance of also addressing the *volume* problems of transport.

8.4. Conclusions on the role of actors

In this part some conclusions are made regarding the role of actors in various understandings of industrial ecology. Of the five different understandings of industrial ecology derived from the literature contributions to the field, four have a focus on developing and implementing the *changes* to industrial systems. The fifth understanding, the resource analysis type, has a main focus on analysis of resources and their flow through society. In this understanding the role of actors is more indirect, through the generation of knowledge, which can form a basis for subsequent changes and improving the industrial metabolism. In the four other understandings the connection to change is more direct, and some conclusions on the role of actors can be made. This is discussed in light of the empirical case material.

8.4.1. Conclusions on actors in the product design understanding

The literature contributions to the product design understanding of industrial ecology indicate that the main actors involved are industrial engineers and designers involved in the design and development of new products with improved environmental performance. The public sector and consumer organisations can also play important roles as pressure groups in demanding more environmentally friendly products, for example eco-labelled products. In addition can branch organisations function as actors by deciding upon standards and codes of conduct pertaining to industrial producers. This can influence the design of products. Responsible Care programs and Product Stewardship codes developed by the Chemical Manufacturers Association are some examples where these actor groups can play important roles.

Case 5 - Alternative mobile energy – can be considered an application of the product design understanding, in addition to its main connection with the resource analysis understanding. In this case actors were identified at two different levels. The first actor-level consisted of outer actors in positions to influence, form and decide on national policies and strategies for alternative fuels in general and biodiesel in particular. The second level consisted of bus companies and the employees at different levels in their organisation. The bus companies are key actors, both in terms of the company as an actor, and the inner actors within the company, at management-, driver-, and garage-level. Both the national actors and the bus companies functioned as sources of information on barriers, and for resolving them, facilitating the implementation of alternative energy in transport.

The case also gives an example of how actor involvement in the area of wood-based motor alcohols can be organised, through the forming of stakeholder group networks. These types of networks can be placed within the concept of *environmental co-operative regimes*. Such regimes had not previously been applied within the area of expanding the use of alternative biological fuels. These are networks where many different actors co-operate in identifying key barriers to the implementation of wood-based motor alcohols, and the resolving of the barriers. Through such stakeholder group networks the actors can agree upon common strategies. In this case the actors agreed upon that the main strategy for resolving the barriers is to establish *co-operative channels* to major governing bodies.

8.4.2. Conclusions on actors in the eco-park understanding of industrial ecology

In the eco-park understanding it is possible, from the literature contributions, to conclude that the most important actors are the individual companies taking part in industrial ecological clusters. The participating companies are playing important roles in the functioning of these industrial systems. In addition to the participating industrial companies, a facilitator of some sort is usually needed for the forming of an eco-park. A facilitator is an actor whose function is to stimulate to the forming of a recycling network and co-ordinate the waste-producers and the waste-consumers (scavengers). A facilitator can be one of the participating industrial companies, but can also be a neutral part, for example the local or regional development council.

Case 1 – Rural SMEs - is representing an application of the eco-park understanding of industrial ecology. In this case it is shown that in rural areas the possibilities for the individual enterprises to take part in the forming of ecological clusters (or “eco-parks”) are restricted. The restriction is mainly in the form of long transport distances. The actor involvement is thus restricted by structural conditions. However, in collaboration with other companies (actors) the restriction can be less severe. The case application thus reveals a problematic side of industrial ecology, clearly seen in the eco-park understanding: Eco-parks are limited to areas where the density of industrial facilities is high, usually close to urban areas. Individual enterprises cannot participate in an efficient industrial ecosystem unless nearby possibilities of waste-for-raw material exchanges exist.

Enterprises located in remote (rural) locations have limited possibilities for such inclusion, without the existence of nearby clusters of industrial facilities.

8.4.3. Conclusions on actors in the CEM understanding

The literature contributions to the CEM understanding point to a wide range actors with important roles. Corporations are the main actors in this understanding. Top management, the middle management with responsibility for quality assurance and long-term planning, and individual employees are contributing to the functioning of management systems. Also governmental authorities can function as important actors connected to the mandatory requirement of some environmental management systems, as supervisory agencies for the regulations. Other governmental actors are involved through law-making processes, such as through the revision of the Norwegian Accounting Act and the Norwegian Limited Liability Companies Act, which both require companies to publicly report on environmental issues. Certifying bodies for standardised environmental management systems, for example Det Norske Veritas (DNV) for ISO 14001 and EMAS, are also important actors.

Case 3 - Transport scenarios in a company strategy and Case 4 - Environmental reporting in a public transport company - represent the application of the CEM understanding of industrial ecology. In addition, also Case 5 - Alternative mobile energy – gives illustrative examples of connected to the CEM understanding, in the form of implementation of strategies for alternative energy in bus companies.

Case 3 illustrates how a transport company can include in their environmental strategy, scenarios for transport development. The public transport company Oslo Sporveier is the main actor in this case. An important actor-involvement aspect is illustrated in this case. Political actors are informed, through the transport scenarios, of the consequences of different developments in public transport. Important knowledge for guiding the development of a city is thus channelled from the public transport company up to the political actors.

In Case 4 it is given examples of how actions and measures for environmental improvements in public transport is identified and implemented. The successful implementation of such actions and measures is highly dependant of the involvement of actors. The actors in this case are found within the public transport company Oslo Sporveier. The components of the organisation are important in this case, and as such this case has a focus on the inner actors, i.e. the actors within the company. The main actors involved are connected to the planning department, with responsibility for the environmental reporting. But a wide range of actors within the organisation is involved, either in the gathering of data for the reporting, or for facilitating the implementation of actions and measures for improving the environmental performance of the company as a whole.

In Case 5 it is shown that the bus companies, and the employees at different levels in their organisation, are important actors, also in connection with the CEM understanding. Actors at the different levels of the company, at management-, driver-, and garage-level were shown to be important for the establishing of strategies for implementation of alternative fuels.

8.4.4. *The role of actors in the factor X understanding*

Even though none of the five cases can be considered a representation of the application of the factor X understanding of industrial ecology, some principal conclusions can be made on the role of actors in this type. In the factor X understanding important actors are connected to technological innovations necessary to reach the goals of major resource productivity improvements. Resource productivity improvements of factor X, especially with high X-values, are likely to be achievable only with strong *government-driven policies*, thus involving actors at the governmental level. The two strategies suggested by Reijnders (1998), of 1) Technology-forcing law and 2) Ecotaxation, are examples where governmental actors are involved through law-making processes and as supervisory agencies for the regulations.

One example of actor-involvement through technology-forcing laws is in the area of improving the energy efficiency of automobiles. The U.S. Department of Transportation, through the Corporate Average Fuel Economy (CAFE) regulations, required all vehicle manufacturers to comply with sets of fuel efficiency standards (Greene, 1990; Schipper and Meyers, 1992). Another example is in the area of automotive emissions of new U.S. cars (Ashford et al., 1985; Grant, 1995).

The strategy of making technology for factor X improvements in resource productivity more attractive by ecotaxation implies that environmental costs are internalised through the taxation system. This is another way by which actors are involved, as supervisory agencies for the tax regulations.

8.5. Final conclusions on problems and prospects

The five different understandings of industrial ecology have revealed theoretical knowledge on relations between industrial ecology and transport. The case applications have in addition illustrated how transport can be addressed within the frame of industrial ecology. Conclusions on the role of actors have been made from those four industrial ecology understandings with particular focus on change, and from the case applications of these understandings.

Some critical reflections on the overall methodology must however be made. The first reflection concerns the *limitations of the cases.* The cases are not ideal for elucidating relations between industrial ecology and transport. The projects forming the bases for the cases were not designed with the aim of throwing light at transport –industrial ecology relations. The projects were first of all designed to study transport problems. This would normally constitute a limitation in the empirical material. But in all the projects the transport problems were studied in connection with industrial systems, and thus provide knowledge relevant for understanding relations between industrial ecology and transport. In addition they study a wide range of transport problems.

The second method-reflection is regarding the *role of the researchers*. The researchers have played an active role and contributed to the design of the projects forming the bases for the empirical cases. The cases are thus not viewed from the outside by "sideline-researchers". This raises some problems. It could for example be argued that this constitute a limitation to the material, in that it can be characterised as having a tendency to be used to confirm ones own understanding of an issue. This can be illustrated by the cases based on empirical material from the public transport company. The researchers had an active role in the defining of what types of transport problems are emphasised in connection with transport scenarios and environmental reporting. This is based on an understanding of what forms of problems are important to address. The material is therefore vulnerable for the criticism about using the empirical material to confirm ones own understanding.

From the theoretical contributions and empirical cases it can be concluded that the relations between industrial ecology and transport is characterised by an overall main focus on the *efficiency* problems of transport. Some examples of these problems include:

- How to improve the energy efficiency of automobiles
- How to reduce exhaust pollutants of automobiles
- How to improve capacity utilisation (load factor) of current transport

Pattern problems of transport are less frequently addressed in the field of industrial ecology. The pattern problems, shown through this thesis to be important to consider in addition to the efficiency problems, include:

- What substitutions in transport means can be made (bus instead of car)? Can bus be used instead of car?
- Can substitutions in transport modes (water-based and rail instead of road and air in goods transport, rail instead of road and air in person transport) be made?
- Can non-motorised (walk/bike) be used instead of motorised transport?

Volume problems of transport have an even lower focus in industrial ecology. Some of the transport volume problems shown in this thesis to be important to address within the frame of industrial ecology include:

- Increase in global transport of goods
- Transport-generation in recycling-systems, particularly in non-urban, non-industrial areas (rural areas)
- The actual effect of telecommunications on transport volumes
- The limits of alternative sources of energy

One might then ask: Could it be argued that, at least in principle, industrial ecology never was meant to include transport? Or, is industrial ecology limited to less fundamental transport questions, only requiring minor societal or individual changes?

Based on theoretical contributions to industrial ecology it is possible to conclude that there is no support for the argument that industrial ecology never was meant to include transport. On the contrary, plenty of examples can be found within the industrial ecology literature where transport is addressed. Several books are written about transport issues within the context of industrial ecology. "Industrial

Ecology and the Automobile" by Graedel & Allenby (1998) and "Industrial Ecology of the Automobile - A Life Cycle Perspective" by Keoleian et al. (1997) are two examples. These contributions are mainly addressing efficiency problems of transport. With the basis in the theoretical contributions, plus the five empirical cases, it can be concluded that industrial ecology has reasonably good prospects for addressing transport efficiency problems.

It would however be possible to agree that more fundamental transport questions, requiring larger societal and individual changes, fall outside the main understandings of industrial ecology. The fact that these transport problems are not often included in the discussion of industrial ecology can be considered a limit for the concept's application. The empirical cases however illustrate that it is not only possible, but also important, to address also the volume problems of transport. It can thus be concluded that industrial ecology has a potential for addressing also these more fundamental transport questions. This potential is however not realisable without a change away from the traditional efficiency focus of industrial ecology, and include more extensive approaches to the problems. A final statement in a recent contribution to the industrial ecology literature is to a large extent in agreement with this general conclusion:

> Our conclusion is that industrial ecology has, as a field, overemphasised cars as products and underemphasized the transport system of which the car is such a major part. An emphasis on private vehicles is easier and more familiar for technologists, but will almost certainly result in unsustainable systems over the long run.
> (Graedel et al., 2002, p. 444)

8.6. References

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